The Design of Large Technological Systems

The cases of Transmilenio in Bogotá and Metro in Copenhagen

Pineda, Andres Felipe Valderrama

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Andrés Felipe Valderrama Pineda
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DTU Management Engineering
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The Design of Large Technological Systems
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and Metro in Copenhagen

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DTU Management
Department of Management Engineering
Technical University of Denmark

Produktionstorvet 424
2800 Kgs. Lyngby
Denmark

Tlf. +45 +45 25 48 00
www.man.dtu.dk

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To Quibi,
Clemencia (mother and father),
Tia Maga, Tia Christy, Tia Go,
Julia,
Luna, Mayté
and Margarita,
the women that made me,
the women I am,
the women of my life.

Me, we. Muhammad Ali
(unspecified date)

The city is not a whole, but a composite entity
(Bender, 2009: 304)

They never teach technology in engineering schools, if they don't teach you to follow a project from the smallest cubbyholes up to the loftiest spheres (Latour, 1996: 142)

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Abstract

This is a study of the processes of design of large technological systems based on a two-case study: the rapid transit bus system, Transmilenio, in Bogotá, Colombia, and the urban rail system, Metro, in Copenhagen, Denmark. The research focused especially on the process by which designers define material scripts during the conception, construction, implementation and operation of large technological systems.

The main argument is that designers define scripts in a process in which three parallel developments are at play: first, a reading takes place of the history (past, present, future) of the arena of development where the system will be constructed. Second, designers define scripts through the delegation of agency, causes and responsibilities to humans and non-humans, a process in which the limits of the system are also defined and enacted. Third, the process of the definition of scripts implies a reconfiguration of the designing team, the supporting actors and the diverse user groups.

By tracing material scripts, the author accounts for the unfolding of visions, politics and materialities that constitute the system. The analysis contributes to understanding the complex sociotechnical dynamics involved in the design processes of large technological systems by revealing how their constitution produces a reconfiguration of the arena of development of urban transport. This dynamic substantiates the co-evolution of technological systems and the city.

Resumé

Dette er en undersøgelse af store teknologiske systemers designprocesser. Den er baseret på to case-studies: hurtig-bus systemet Transmilenio i Bogotá, Colombia, og bybanesystemet Metro i København, Danmark. Undersøgelsen fokuserer især på den proces, hvor designere definerer materielle scripts under udformningen, konstruktionen, implementeringen og driften af store teknologiske systemer.

Hovedargumentet er, at designerne definerer scripts i en proces, hvor tre parallelle udviklinger er på spil: For det første sker der en historisk læsning, det vil sige at fortid, nutid, og fremtid af den udviklingsarena hvor systemet vil blive bygget undersøges. For det andet, definerer designere scripts via en uddelegering af agency, årsager og ansvar for humane og ikke-humane. Denne er en proces, hvor grænserne for systemet også bliver defineret og enacted. Endelig indebærer processen af definitionen af scripts en omstrukturering af designerteamet, de støttende aktører og de forskellige brugergrupper.

Ved en opsporing af de materielle scripts redegør forfatteren for udfoldelsen af de visioner, politikker (politics) og materialiteter, der udgør systemet. Analysen er et bidrag til forståelsen af de komplekse sociotekniske dynamikker involveret i design processer af store teknologiske systemer, ved at afsløre, hvordan disses tilblivelse producerer en omstrukturering af udviklingsarenaerne for bytransport. Denne dynamik underbygger tesen om teknologiske systemers og byens fælles udvikling.

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Two persons have been essential in making my intellectual development, the writing of this document and the world worth living in possible: they are my supervisor, Ulrik Jørgensen, and my wife, Julia Suárez Krabbe. Many parts of this text are indebted to them in many ways. Living in Denmark has been a delightful experience that would not have been possible without their unconditional support.

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Being a Ph.D. student and having a family are of course not incompatible in Denmark, where graduate students have three things that are fiction to many of my colleagues in other European countries, in the United States, in Argentina and in Colombia: they have decent salaries; they have rights; and from the outset, they receive support to participate in international academic events. I consider these the best conditions in the world for developing a Ph.D., and I truly hope that the Danish academic community succeeds in maintaining and improving them. This research was possible thanks to a full scholarship provided by the Technical University of Denmark. Other institutions that supported this research financially are: Fund Idella and Fund Otto Mønsted in Denmark; and Universidad de Los Andes in Colombia.

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1. Introduction

This is an article based Ph.D dissertation. I have developed five articles which the reader can find in the appendix. The purpose of the main text is to substantiate and complement the developments of the articles. In this first chapter I will present a justification and outline of the research problem, the purpose and scope of the research, a justification of the cases, and an outline of the following chapters. The reader can choose to read the articles before reading the main text of this dissertation, or to read them as they are referred to.

1.1 Justification and outline of the problem

The problem I address in this dissertation is the classical engineering problem: how do we conceive, design, construct, operate and eventually disassemble a working system. This has been my main professional concern since I finished secondary school and thereafter studied mechanical engineering. During my years as an engineering student, I did not obtain a convincing answer to this problem. Instead, I was taught a wide range of specific knowledge: how to model an ideal system using mathematics; how to design several shafts for dynamic loads, taking into consideration long-term effects, like fatigue; how to choose bearings from a catalogue; how electric, thermo and hydro machines work under different conditions; how circuits work; and a good deal of theoretical dynamics of solid objects, solid mechanics, fluid dynamics of simple layered ideal fluids, heat transfer, thermodynamics and aerodynamics. No doubt these are valuable areas of knowledge, but I received no instruction in how to integrate all this knowledge into the development of a project: too much analysis, no synthesis.

It seemed too discouraging, what teachers and employers said at the time (and they still repeat it today): the main thing necessary to conduct a project is political support; otherwise, the technical job is not possible. If this is so, are engineers and designers then powerless professionals? If this is so, does theory play only a subsidiary role? Is the main task of engineering outside the reach of theoretical systematization? Or in other words, is it impossible to possess knowledge about what is necessary to realize engineering projects? Also, is it a concern only for professional engineers, or could it possibly be an interdisciplinary and multicultural academic task?

Many of my colleagues at the Engineering School of Universidad de los Andes, where I worked for five years and where this project was born, also shared my concerns and the frustration of not finding answers in their own fields of research and teaching. This frustration was (and still is) shared by many engineers and engineering educators in the world (NAE, 2004). Perhaps the problem is related to the fact that engineering educators have pushed the social and political aspects of engineering outside the curriculum (Downey, 2005). To find answers, I have reached out to different fields, including management-related theories, history of technology and science and technology studies. I have been fortunate enough to come across a number of scholars in the world that also share the same or similar concerns through research in these fields. It is in academic dialogue with them (some are named in the acknowledgements

and the references) that I have undertaken the task of scholarly investigating of the above questions.

The principle that engineering works – along with technology development and scientific knowledge – are the result of interaction among humans and non-humans (Latour, 1996) or of "components, some of which are not technical" (Hughes, 1983: 6) is widely shared in fields like History of Technology and Science and Technology Studies (STS). Furthermore, scholars working in these fields realize that technical decisions and technical practice are not merely technical, but also political, social and economic. However, a theory that approaches decisions by trying to isolate the technical aspects from the social aspects will from the outset incur the transgression of analytically imposing differentiations that are not there when the engineering work is being developed (Akrich, 1992). Therefore, scholars in the fields mentioned have taken pains to develop new concepts to account for the variety of sociotechnical dynamics involved in the conception, design, construction and operation of engineering works. In this dissertation, I draw mainly (but not exclusively) on the theoretical developments of the Large Technological Systems tradition (LTS) and Actor Network Theory (ANT) and further conceptualisations like that of arenas of development. I study the process of design of two LTS', also to show how specialized knowledge of engineering plays a key contributing role, which can only be understood by tracing the activities of the designers and how they put together heterogeneous elements for specific features of the system.

There are engineering projects of different sizes. I have chosen to focus on projects that meet two criteria: they are present in our daily lives, and they affect the ways society is organized in a very visible way. Although there is value in analysing communities of physicists that study gravitational waves (Collins, 2004) and other esoteric enterprises, there is also a strong need to investigate the technologies that are shaping and re-shaping social life as we know it here and now (Martin, 1993). Transport systems in urban settings meet these criteria. And for this project, I chose to study Transmilenio in Bogotá and Metro in Copenhagen (see section 1.3 for a justification of this selection).

1.2 Purpose and scope of the research

There are many aspects of such projects as Transmilenio or Copenhagen's Metro that are worth investigating. Some might be tempted to look for the essence of a project –the technical idea, the leading concept – and its historical genesis to account for the conception of the project. Others might want to understand the socio-political dynamics that framed the problem that was then posed to engineers. The first approach would adopt an internal view of the task; conversely, the second approach would place emphasis in the factors external to the project. The approach that I chose for this analysis aims to overcome the distinction between in and out, technical and social. Thus, my choices where guided by the aim of analysing the ways in which design decisions are technical and political at the same time and how.

Linear models of planning and design state that there are eight distinct phases in a design process (Dym, 1994): definition of the problem, formulation of objectives, conceptual design, definition of alternatives, selection of the best alternative, detailed design, construction and operation. Promoters of these models also state that the

technical decisions also become increasingly important from the conceptual phase onwards. Visions and objectives are defined in the first two phases presumably in a more political way. However, an increasing number of studies show that such sequential processes are the exception rather than the norm (Jensen and Andreasen, 2010). Furthermore, case studies and empirical analyses show that the overlapping in time and the overlapping in the distribution among teams and persons of tasks that analytically belong to different phases blur these sequences phases, if they exist at all (Ardila-Gómez, 2004; Hughes, 1983, 1998; Latour, 1996). To clarify, I am not stating that the linear model is not valid or that it is fiction; I am stating that there is much more to design than the phases presented in normative linear models (Akrich, Callon, Latour, 2002). The linear model is used and might sometimes be helpful, but in this dissertation, I want to research issues that are not captured by the simplified model.

In this dissertation, I propose to account for the sociotechnical process of defining some features of large technological systems, which may appear to be only technical once they are stabilized. A thorough analysis of all the design features of a project of the size and scope of an urban transportation system is a monumental work and perhaps an unnecessary task (Akrich, 1992: 206). The aim is therefore not to provide a comprehensive account of all the material characteristics of a system, but to research a few of these characteristics in order to account for the *nature* of the process of defining design features. I have therefore chosen to focus in the design aspects of Transmilenio and the Metro that best fit the analytical objective of this research: to account for concrete working features of the transportation systems that are apparently uncontroversial.

As an engineer, as a user, as a citizen, there are many questions about concrete features of transportation systems that puzzle me, although they have become relatively stable: Why is the Metro automatic? Why is there no driver or steward on board the vehicle? Why are the overground stations of the Metro open? Why do the buses of Transmilenio use diesel engines? Why are the bus stations of Transmilenio in the middle of the roads? Why does the whole system have a high platform? Why do these systems cover certain parts of the city and not others? Why was access carefully guaranteed through the design of the trunk lines of Transmilenio, but not the feeder lines? What is a good map for navigating an urban transport system? I could add many more questions to this list, but I chose these for three main reasons.

The first reason is that I decided to focus on visible “stable” design features and engage in interviews and dialogue not only with higher ranking system builders (mayors, project leaders), but also with middle level engineers, technicians and stakeholders. My aim here was to go beyond the great narratives that system builders always develop as a strategy to make their projects more solid. This is not, of course, a minor aspect of project development, and it has certainly been discussed (Latour, 1987, 1996), but I wanted to reach into the actual engineering and design work: the process that produces the system and its narrative.

The second reason is that I did not want to focus only on openly controversial aspects. Akrich (1992) states that design aspects about which there is visible and open disagreement, negotiation and the potential for breakdown are the best ones to

investigate, in order to analyse them in proper sociotechnical terms (using a vocabulary imported from semiotics, which I introduce later on). However, these analytical tools should also be valid for analysing those aspects of design, or those decisions, which apparently rapidly became stable. This is my purpose in this dissertation.

The third reason is that focusing on specific elements functioned as an appropriate entry point for interviews and text analysis, since it provided a device to navigate in the networks of actors. Interviewees responded to my questions and pointed out other actors that were relevant in relation to the issues I was tracing. I maintain that following the definition of scripts (Akrich, 1992) is a valid way to follow the actors (Latour, 1996) in a design process, and this is the methodological foundation of this study (see section 4.1).

Briefly and schematically, the main theoretical question is:

> How do designers conceive and define the main features of urban transportation systems?

The fact that I am researching urban systems has given a variable geometry to the object of my study. Focusing on the Transmilenio also requires researching Bogotá as a city, and the Metro entails examining Copenhagen. This has surfaced in my findings in two important ways: first, in a compulsory connection between my research and the current discussion between urban theorists and science and technology studies scholars about the possible cross-fertilization of these fields. My main challenge here is to re-conceptualize urban transport as an arena of development, where the design of new systems necessarily implies the reconfiguration of whole transport systems in both cities and thus of an important part of the cities themselves (Valderrama and Jørgensen, 2008; Valderrama, 2009). At the same time, the size and character of the systems I study imply that they are part of a bigger transformation of the cities, which provides the opportunity to discuss how system and city co-shape each other. Furthermore, passengers and urban commuters cannot be viewed as mere passive users (Oudshoorn and Pinch, 2003; Rose and Blume, 2003). In both Bogotá and Copenhagen, residents have taken pains to use, affirm, resist, suggest improvements, etc. to many of the features of these transportation systems. They have participated actively in the design of the urban transportation in their cities, and in this dissertation I also analyse their role (Valderrama, forthcoming; Valderrama, forthcoming a).

1.3 Justification of the selected cases

I investigated the question of design of large technological systems through the analysis of two cases: the design of Transmilenio in Bogotá; and the design of the Metro in Copenhagen. I selected these two cases, because they share a number of interesting features. First, from the outset, these were not minor projects to maintain or improve existing patterns of mobility (see figures 1 and 2 for a few basic data for these two systems and their cities). These were the cities' major projects, aimed at producing considerable change in the momentum of the developing trends of mobility in both cities. Among other things, both projects aimed to curb the use of cars and considerably improve the provision of public transport in their cities as a whole. Due to their

character and size, and thus the resources they required, they were discussed at both the city and national levels, which meant that they also had a considerable impact on the governance traditions for carrying out such projects in both cities and both countries (see section 3.2).

A second reason for the case selection is that both projects exhibited innovation. Copenhagen's Metro is the first fully automated rail system to provide service to a capital city; and Transmilenio is the first *mass* rapid transit bus system to achieve performance levels previously only possible with urban heavy rail systems (Wright and Hook, 2007: 73; Gilbert, 2008). Both cases, therefore, implied an additional quota of risk for the designers, since they were not only departing from their local transportation traditions, but also experimenting with new technologies. During the research, I discovered that the innovation was only made possible because the planners had carefully built a protective space from traditional control organisms in both cities. The technological innovations also required innovations in organization and strategy which I will characterise as an extended laboratory (see section 3.2).

Figure 1. Layout and main statistics of the Copenhagen Metro. Information retrieved from Metro's official webpage www.m.dk

A third reason for selecting these cases relates to access to documents and interviewees in order to gather the information necessary to proceed with the analysis. Before moving to Denmark in 2006, I had contacted many Transmilenio planners and performed some interviews, and I had already retrieved relevant documentation. Living in Copenhagen granted me access to information on the Metro case. Also, my supervisor's previous engagement in research regarding the design of the Metro provided a basis for consolidating the selection of this case.

It is worth noting, however, that this study is not a comparison of the final design and technological features of the two sociotechnical systems, using ossified and essentialist notions of scale, space, technology, city, agency structure or identity (Graham and Marvin, 2001; Coutard, 2005: 48). The intention was to carry out a two-case study (Yin, 2002). In other words, I did not select, *a priori*, a series of categories to examine in each case and then compare them. Instead, I applied case study principles to each case in order to investigate the research question. In fact, at the time of writing this, the depth of

analysis is greater in the Transmilenio case than in the Metro case, Transmilenio is to be seen as the main case, and the Copenhagen Metro as a control case. Flagging similarities in the design process of two different transport systems by two very different communities of engineers in two contexts that have very little in common is a way of testing the relevance of case studies (Flyvbjerg, 2006). The design processes of Transmilenio in Bogotá and Metro in Copenhagen share some features that will become clear through the study of each case. In this fashion, I avoid basing the comparison on external "social", economic, political or technical features. Instead, I analytically focus in the process of design, which is the true object of study of this dissertation.

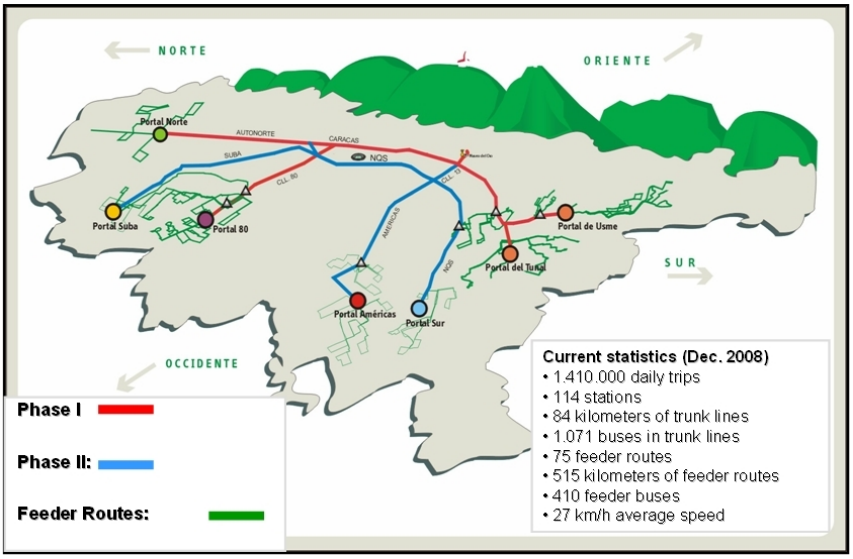

Figure 2: Layout and main statistics of Transmilenio. Information retrieved from the General Presentation (Power Point) of Transmilenio S.A. December 2008.

1.4 Outline of the dissertation

This Ph.D. is based on articles. The main advantage of this format is that the number of scholars involved in the research increases, since supervisors and evaluating committees are complemented with the publications' editors and referees . It also fits better with the fact that science is communicated knowledge. The downside of such a strategy is that articles have to be short and in many cases do not provide the opportunity to discuss thoroughly the theoretical grounding of the concepts used in the arguments. Publishing also takes time, and a three-year period can be too short for any researcher to produce a fully coherent dissertation made up of published articles., It is also true, however, that many monographic dissertations in book form result from articles that with time and some extra work present a coherent argument (e.g. Law, 2001; Vincenti, 1990). In the hope of progressing in that direction, this dissertation is based on five articles: three already published and two drafts.

In the first article "Diesel versus compressed natural gas in Transmilenio-Bogotá: innovation, precaution, and distribution of risk" (Valderrama and Beltran, 2007), a colleague and I asked why the buses of Transmilenio were powered by diesel engines. We chose to concentrate on one specific script to reconstruct the way this was discussed and decided. To our surprise, this decision, which seems quite solid when using the

Transmilenio system, was full of uncertainties and was actually not that stable, depending who was asked. In fact, various designers and would-be stockholders of the transportation system were involved all the way from the beginning to the end of the design process. The article's main argument is therefore that while different actors negotiated a technical feature, they simultaneously negotiated a certain distribution of responsibility. More specifically, the city administration – represented by the planning team of Transmilenio – adopted the position of not deciding the type of engine but made the private operators of the system responsible for meeting timetables and transporting a specified number of passengers. The private operators had the freedom to choose compressed natural gas or diesel engines. They all chose diesel engines, because at the time, this technology had lower financial and environmental risks.

In the second article "Urban transportation systems in Bogotá and Copenhagen: An approach from STS" (Valderrama and Jørgensen, 2008), my supervisor and I explored the theoretical possibility of linking two concepts to account for what we identified as the twofold character of design decisions: first, they distributed agency among the actors that make up the system; and second, they responded to features of the existing local arena of transportation development at the time, establishing desired continuities or desired differences. This twofold process explains the particular configuration of what became the boundary of the transportation system. We illustrate these dynamics by examining the decisions to adopt a high platform for the Transmilenio system in Bogotá and an automatic train for the Metro in Copenhagen. We also examined the process of defining the routes in the first phase of these systems in their respective cities.

In the third article "How do we co-produce urban transport systems and the city? The case of Transmilenio and Bogotá" (Valderrama, 2009), I extended the analysis proposed in the previous article regarding the case of Transmilenio in Bogotá. I introduced the concepts of script, inscription, description and pre-inscription proposed by Akrich (1992) to account for the processes of producing specific design features and the ways these processes reconfigure the arena of transportation development in Bogotá and enact the boundary of the new system. In this article, I develop more details about this case. These last two articles interested scholars working with the relations between urban studies and architecture and science and technology studies, which explains the character of the volumes in which they were published. Therefore, they also discuss how the design of new transport systems of the size and character of Transmilenio in Bogotá and Metro in Copenhagen is one important element in larger urban transformations. However, these transformations are not to be understood as parallel unconnected processes, but as related developments that constitute the same complex transformative process. Using the concept of arenas of development, my supervisor and I attempt in both articles to present the details of these dynamics. This is discussed in section 3.5.

In the fourth article "Accessibility in urban transportation systems: an STS approach" (Valderrama, forthcoming), I investigate the definition of some scripts that constitute the accessibility of the system Transmilenio. I pay particular attention to those aspects in which designers delegated responsibility for granting people in wheelchairs access to the system. I show how the process was controversial and uneven: some features were implemented in parts of the system but not in the whole. Representatives of a concerned

group (of wheelchair users) were able to influence the design, but only after appealing to a legal instrument called *tutela*, which grants individuals legal and political opportunities. During the discussion of this legal action, the system builders of Transmilenio deployed financial and economic arguments to justify the lack of access to feeder lines. The higher courts finally decided in favour of the concerned group, but until now access to the system for people in wheelchairs is still only partially guaranteed.

In the last article "The Map of Transmilenio" (Valderrama, forthcoming a), I deal with the design of the map of Transmilenio. This inscription is of special interest, because it aims at representing the whole system, in order for users to navigate it. Several actors met and struggled to influence the character, principles and final outline of this document: the Transmilenio operations experts who wanted to maximize the performance of the system as a whole; the communications experts of Transmilenio and their supporting consulting staff at Steer Davies and Gleeve in London, who had particular views regarding the users, based on a whole body of knowledge on signage; and the various groups of users themselves, who participated in different ways, including a webpage forum. The analysis of this document reveals how users actually struggled to influence the design of the whole system, and how the system builders of Transmilenio dealt with these efforts.

In the articles, I have predominantly used the Transmilenio case to illustrate my arguments. In the body of this dissertation, I draw on aspects of the design of the Metro to develop my arguments.

Section 2 provides three basic elements for the better understanding of this dissertation: a presentation of the object of study (section 2.1), a brief outline of the existing scholarly work on the two cases (section 2.2), and a brief introduction to the main aspects of the theories that constitute the point of departure for this dissertation in the field of science and technology studies (section 2.3). In section 3, I develop five key aspects that support and complement the arguments of the five articles: 1) the theoretical articulation that justifies the triangulation I am attempting between large technical systems theory, actor network theory, and arenas of development (section 3.1); 2) how the actions of the different actors involved were organized in an extended laboratory where knowledge was accumulated, and how that space for the coordination of action was protected (section 3.2); 3) since the concept of arena of development invokes the role of other transport systems, it is necessary to account for their participation in more thorough terms and explore what I consider to be the missing symmetry of symmetrical analyses (section 3.3); 4) I research the ways in which different design actors and users interact (section 3.4); and 5) although my analysis belongs mainly to the science and technology studies field, it might also interest urban studies readers, so in section 3.5, I discuss further the possible contributions of my analysis to urban studies.

Section 4 is devoted to discussing the methodological grounding of my study as a case study research, drawing on the principles and some elements of ethnomethodology and grounded theory and data collecting methods. Finally, in section 5, I summarize the main findings of this research, what I consider to be the most important reflections that

follow from it, a set of tasks for the future development of this research, and a few more general remarks about the possible implications of this particular research for the various fields it might interest. The reader can find a list of interviewees and references in section 6, and the complete texts of the articles that form the basis of this dissertation in the appendix section.

2. Concrete problematization of this research

2.1 The Design of Large Technological Systems

In order to investigate the question – How do designers conceive and define the main features of urban transportation systems? – I have concentrated on analysing the process of conceiving and defining features – that is, the design process. Two further elements have been equally important: who might be considered the designer actor; and what is designed. Let me take these three elements (subject, verb and object) of the research question one by one, in order to make the scope of this research as precise as possible for the reader.

The process: conceive and define

While the verbs "to engineer" and "to plan" appear in the literature, design is increasingly used to refer to the production of systems, devices, infrastructure and even events in the urban milieu. Therefore, I have chosen the verb "to design" to refer to the process for three reasons: first, etymologically, design also means defining the sign (de-sign), or assigning meaning, or defining the script. Because one of the intentions of this dissertation is to account for the definition of concrete stable features of technological systems, it is appropriate to call the process under scrutiny "to design" or designing (see section 3.1).

The second reason is that design has been an engineering concern for a long time. Since the 19th century when the engineering profession became of central importance in many countries, there has been a focus and concern for design in engineering. Unfortunately, due to complex historical developments since the middle of the 20th century, the concept of design of technologies and systems has disappeared from research agendas and educational programmes, which instead concentrate on analytical tools and specialized knowledge production. During the last 20 years however, many groups of engineers and engineering educators have struggled to restore design to both the research and education agendas of engineering schools (Bronet et al., 2003).

Since I belong to one such institution, my third reason is: I developed my research at the Department of Management Engineering of the Technical University of Denmark. Over the last ten years, some scholars in this academic unit have conceived, developed and conducted an education that combines engineering, design and science and technology studies. They have been successful in educating a type of professional engineer-designer that combines many features of these traditionally separate profiles: good technical grounding and the capacity to produce sound design concepts and aesthetically grounded products and systems. These professionals are also well qualified to work in teams (in contrast to the archetypical individual artist-designer); and they are aware of and able to mobilize the relevant actors needed for any given design or potential project (Alting et al., 2006; Boelskifte and Jørgensen, 2005; McAloone, 2007).

Because my objective is to account for the sociotechnical dynamics of the process, I will approach designing from a specific point of departure: Science and Technology

Studies. Thus, I refer to design as the process of conceiving, building and operating a transport system *and* the world in which it functions. This means that designing is a process of co-production (or co-evolution or co-construction) of technology and society (see section 3.1 for a distinction between these terms). Therefore, this study will depart from normative models of designing. These models are common in designing literature and fulfil a research and educational function providing ways to discuss the process. They also attempt at ordering the technical details of the process. However, the models tend to be ideal types that leave out many elements that come to the fore through case studies of practiced design, especially the ways in which the technical is also social and political, which is my primary interest in this dissertation.

The Designed Object: Urban Transportation Systems

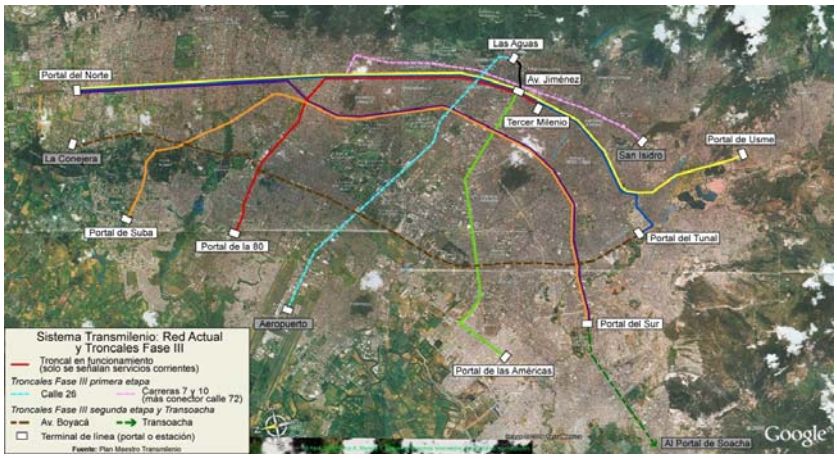

Figure 3: Satellite picture of Bogotá with highlighted operating and under- construction trunk lines (available at http://img142.imageshack.us/i/bogtm063py.jpg/).

What is designed? In the case of this dissertation, I state that designers co-produce the transport system and the city. The designing actor in Colombia produced both Transmilenio and a new Bogotá. In Denmark, the designing actor produced Metro and a new Copenhagen. The strength of this statement can be substantiated by visual inspection in both cities, by looking at satellite maps of the places, or by digging into some statistics. Figure 3 shows how the Transmilenio system has grown to cover a great part of the city, positioning itself as the main structuring element of the public transportation system of the city. Figure 4 shows how the automatic high frequency, high-end Metro system makes it possible to incorporate Ørestad (the dark elongated urban area to the south) as part of the city centre of Copenhagen (the round dark compact area in the center), which is thus doubled in size with this new town.

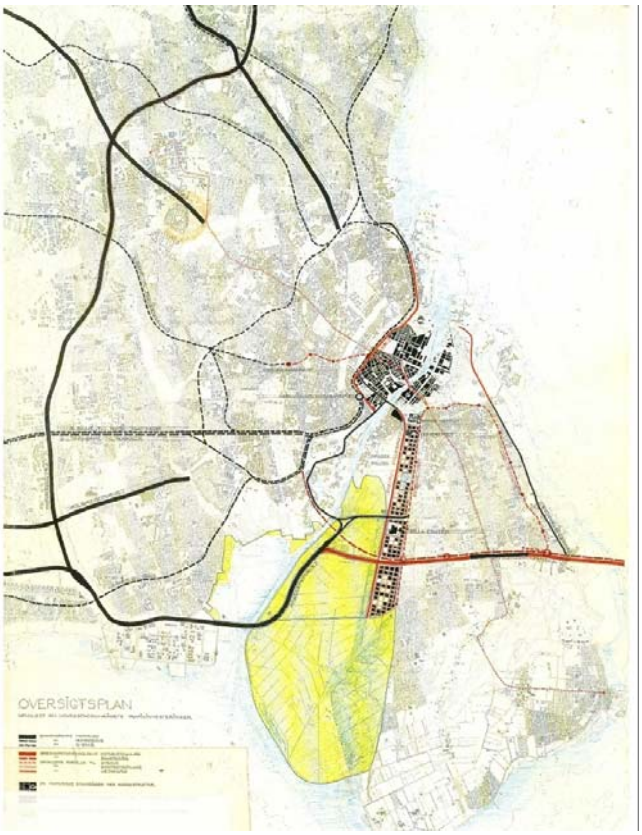

Figure 4: Front cover of the report “Udvalget om Hovedstadsområdets trafikinvesteringer” exhibiting the city centre of Copenhagen, and the then projected new town of Ørestad (various authors, 1991).

The co-production of urban transport and the city happens at two levels. On the one level, it is important to understand that urban transportation systems, such as the ones considered here, are sociotechnical systems. They are not just a technical arrangement that delivers a supportive service to the city. They *are* the city. In fact, the concept of the city needs to be broadened to include the moving city. Inside buses and metro carriages, urban life develops, just as it does anywhere else in the city. These systems also interact, even with those who do not use them: they are part of the urban landscape or cityscape; they cost tax money; they enable fluxes; they are barriers to other fluxes; and they may also be branded and become city icons.

The other level has to do with the continuous transformation of the cities. These systems were part of a major transformation in both Bogotá and Copenhagen. Not only were they considered in long-term plans for their cities’ development, but in many ways their construction, affected the nature of the plans themselves: they shaped each other (see section 3.5).

In section 2.3 I will present the theories that allow me to designate the transportation systems I am studying as actor-networks and as large technological systems that take place in an arena of development. I chose these concepts because they allow to picture the ways transport systems and cities are shaped when designers define scripts. These concepts are useful because they capture the *unboundedness* of these objects and place

emphasis in the process of their becoming and their interrelatedness, rather than their finished features.

Who does the designing? The designer actor

Designed objects and systems are always the result of a multitude of actors. This is especially true for urban transportation systems. In both Copenhagen and Bogotá, there was an initial planning team or core team of system builders: a group of people in charge of gathering the knowledge necessary to coordinate the action of all the other actors. These initial groups were strongly supported by the city administrations, especially the mayors in both cities, but also politicians in the city councils and at the national levels in ministries and legislative bodies.

The designer actor coordinated the activity of local and international groups that participated in defining the features of the systems, deploying specialized engineering and management knowledge. They also coordinated the actual construction of the systems. Thus, my focus is on this core group, which exhibited multiple competences, backgrounds, roles and knowledge-building strategies when defining scripts, delegating agency and thus re-shaping the arena of development of transport in their cities as I will show in this dissertation.

However, I will argue that the designer actor is variable, rather than stable. As it grows from being a few people with a vague idea to a project with support from various other actors, the designer actor will increasingly have the possibility of inviting others to participate in the project also as designers. And the designer actor will also develop an increasing capacity to reject actors that would like to become part of the team. I will provide examples of both types of actions (inviting, rejecting), and will show that the whole process is intimately interlinked in the definition of the scripts that constitute the technological system.

Additionally, non-human actors also constitute the designer actor. In fact, institutions, existing urban designs, existing technological developments and other non-human actors will influence the definition of scripts and the re-configuration of the arena of development, and thus the city. I will introduce a formal definition of all the terms in section 2.3, but first let me present some of the relevant studies that exist on Bogotá's Transmilenio en Copenhagen's Metro.

2.2 Previous work on Transmilenio and Metro

There is already a wealth of literature on different aspects of Transmilenio and the Metro, focusing on technical details, assessment of the systems, economic performance, and many other issues. A few studies however focus in the actual design or planning process of these systems. Inasmuch as this research has been shaped by the knowledge provided by such previous works, and because the main contribution of this research is related to these works, I present here their main arguments.

Transmilenio

Arturo Ardila-Gómez developed a study of the planning process of Transmilenio as part of his Ph.D. dissertation at Department of Urban Studies and Planning at the Massachusetts Institute of Technology in Boston, USA (Ardila-Gómez, 2004). This study is particularly relevant, because Ardila-Gómez focuses in the roles that planners play in the actual planning process to account for its complexity. His study criticizes a tradition in planning theory of viewing planners as mere carriers of political will, technically supporting a plan or project that is defined in the political sphere. His main point is that planners, in this case the core of professionals that steered the planning of the Transmilenio system, act technically and politically at the same time.

Planners can actually perform planning if they belong to embedded, capable agencies: those that "blend political and technical capacity" (Ardila-Gómez, 2004: 28). From there, planners can interact with stakeholders and politicians, which are the other two main actors Ardila-Gómez defines in his analysis. These capable agencies can achieve a minimal space for action, if they are able to take advantage of a window of opportunity. Their main tasks should be directed toward mediating, in order to reduce power imbalances between actors and to adjust the plan to reflect legitimate interests for the purpose of building a coalition of support for the plan or project. According to Ardila-Gómez, a window of opportunity can be caused by big political events like elections or crises. The notion of window of opportunity accounts for the criticality of time: it is not always propitious to pursue a given plan.

Planners' roles are different before and during the opening of a window of opportunity. Before a given window of opportunity opens, planners have three roles: to craft plans, to introduce flexibility in them, and to build a minimum supporting coalition within the expert community. When the window opens, planners can begin to interact with stakeholders and politicians. The interaction becomes a source of feedback of information for all actors. Planners mediate between politicians and stakeholders, "finding ways to hold meaningful negotiations and persuading actors on the convenience of the plan" (Ardila-Gómez, 2004: 385). In turn, planners use collected information to adjust the plan incrementally. For Ardila-Gómez, "it was the politician who knew or interpreted the objectives of the plan" (2004: 386, 400). However, Ardila-Gómez moderated this statement by saying that "meaningful and broad goals emerged from the interaction between planners, politicians and stakeholders" (Ardila-Gómez, 2004: 401).

Ardila-Gómez's empirical analysis and the wealth of detail regarding specific technical decisions are a valuable contribution to studies of large technological systems. Additionally, his focus on interaction among actors in the planning of a working system opens for the exploration of negotiations and politics in technical decisions. His choice of a framework that states that a project becomes real through technical work, political praxis – i.e. the balancing of power among related actors – and the production of legitimacy is certainly appropriate for approaching real practices and thus build a grounded critique of established normative assumptions within the planning and engineering community.

However, the group of actors in Ardila-Gómez's work is limited to politicians, planners (understood as the core group of planners), and stakeholders (understood mainly as the bus company owners in Bogotá). As a consequence, his analysis does not contemplate end users or special groups' participation or non-participation. Also, while he considers the identities of the actors to be stable in his proposed framework, his empirical material shows that identities of these core groups can vary: individuals become part of the planning team and grow inside the team; and bus company owners change their character and position and their identity throughout the process. While Ardila-Gómez states that capable agencies *have* structure, funding, human resources and knowledge from the outset (2004: 23), his empirical material reveals that they *become* capable as the result of interaction. His definition of window of opportunity places agency only in events external to the process that send planners back to a subsidiary role, although his empirical findings force him to admit that "project champions can … extend the window of opportunity" (Ardila-Gómez, 2004: 382). Ardila-Gómez also fails to account for the fact that moving from a plan based on imperfect information to one with more and better information through interaction is precisely the process of knowledge accumulation that three decades of science and technology studies have characterised as much more than simple "information".

Finally, Ardila-Gómez states that planners hired other experts to produce information that would reduce uncertainty among the actors involved – for example estimates of risks associated with demand, load, costs etc. In this way, Ardila-Gómez contends, planners balance power among interest groups and broaden the coalition of support so that it reflects legitimate interests and not vested interests. Although this way of linking the process of knowledge production with politics is interesting, it is in my view an oversimplified picture of the ways in which the technical is also political. These shortcomings in Ardila-Gómez's work seem to be the consequence of a too narrow understanding of actors, power and interaction. In section 2.3, I explain how STS theories and methods provide a richer basis for the development of a more robust framework to investigate the role of planners or designers in the process of designing large technological systems.

Metro

There are two articles on Copenhagen's Metro which are worth presenting at this point, as they approach the development of this technological system from a theoretical framework that is sensitive to the principles I will use in my dissertation. The articles are Tove Frederiksen's analysis of the selection of a fully automated metro technology for Copenhagen (1996), and Ulrik Jørgensen's and Birgitte Munch's analysis of the expectations that were cast in the constitution of the system as an actor itself (2001).

In her analysis of the process of selection of technology for the Metro in Copenhagen, Tove Frederiksen (1996) builds upon the assumption that making a decision is not based on a single rationality, but that there are multiple rationalities at play. These rationalities "are the actors' [or social groups'] perception of problems and solutions … with respect to transport planning" (Frederiksen, 1996: 1). In the case of the Metro in Copenhagen, she concludes that the three competing alternatives were embedded into three different planning rationalities that competed in the city at the moment (Figure 5).

The planning rationalities' importance and extension stretch out in time, as they are also the result of local historical developments. They also refer to heterogeneous social groups or actors and include firms, people, politicians and governmental officials. For Frederiksen, the choice of the mini-metro technology (driverless automatic train) is the result of the success of the social group members (who share, and are organized around, a traffic growth rationality) in designing an institution (Ørestad Consortium) that could structure and justify their option. This process benefited from the previous dismantling of other institutions that represented or were affiliated with the other rationalities – for instance the abolition of the Greater Copenhagen Council in 1990, which was strongly related to the traffic needs rationality.

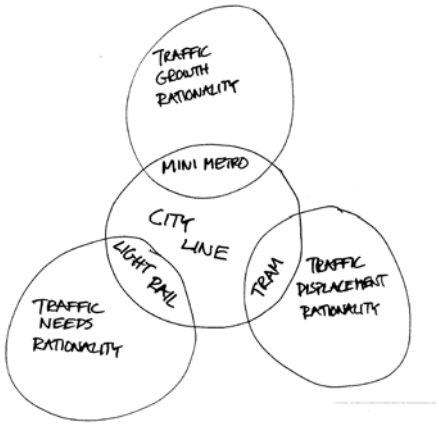

Figure 5: Illustration of the relation of alternatives and rationalities in the process of selecting technology for the Metro in Copenhagen (Frederiksen, 1996: 10)

Frederiksen's analysis links rationalities, power and interaction in the analysis of what is normally presented as a technical decision. It introduces a long-term perspective in the analysis of decisions with the concept of a rationality related to a social group or actor that develops over time. In her analysis, however, the main characters are the rationalities themselves, which add up to organizing principles of such complex processes as knowledge development or institutional design. This is problematic, because it might seem that agency resides in the rationalities themselves and not in the networks of actors that constitute them and invoke them to move their proposals forward.

Another contribution to analysing the Copenhagen Metro in relation to the many contradictory objectives it was supposed to fulfil was taken by Munch and Jørgensen (2001). In their study, they state that

> [t]he socio-technical set-up has been constructed so that that the new Metro is expected to improve and reduce the pressure on the existing transportation system in Copenhagen, and at the same time create a new transportation pattern. The Metro is thereby made an independent actor in city and traffic planning in Copenhagen. A major task has been delegated to this socio-technical entity. It is to create rising values, workplaces, income, and housing in Ørestad, up to a certain level but not more. (Munch and Jørgensen, 2001: 41)

The article proceeds to analyse how the Metro as an actor was weakly supported to fulfil the delegated tasks. From an engineering point of view, the passenger forecasts using origin-destiny matrixes were not realistic. From a user perspective, the new town of Ørestad was supposed to attract mainly workers, and to a lesser degree also residents, and at the same time assumed that they would use public transport and not cars. Many researches showed at the time that these were unrealistic assumptions. Also, a large mall was constructed in the new town, attracting more passengers to the Metro, but also more visitors in cars. The authors therefore conclude that the Metro was expected to deliver in relation to various contradictory objectives, and it was provided with weak support from other actors to fulfil its role.

Munch and Jørgensen's analysis is based on an Actor-Network type of analysis. For them, the Metro is an entity resulting from the interaction of many human and non-human actors, like planners, cars, passengers, traffic forecasts, etc. The quality of the connections and the solidity of the contributing actors will determine whether the Metro is capable of delivering the expected performances to fulfil the different objectives. In this case, they show how the nature of the actors that constitute the Metro contradicts with the objectives and the expectations of the system. I develop this argument further by examining several scripts for the Metro (and Transmilenio) (see section 3.1).

2.3 Points of departure in STS: LTS + ANT + AofD

In this section, I present the principles and main concepts of Actor Network Theory (hereafter ANT), Large Technological Systems Theory (hereafter LTS) and Arenas of Development. These theories provide the basis for the analytical framework and the developments of this dissertation. Through the analysis of case studies in engineering design and engineering projects, these theories are of direct relevance to this study. Therefore, I find it appropriate to use the analysis of the electric vehicle by Callon (1986; 1987), Aramis by Latour (1996) and the Central Artery and Tunnel of Boston by Hughes (1998) as the articulating elements of this section. Although these studies might seem outdated, the fact that both theories are still much discussed (perhaps ANT more than LTS) provides a justification for a return to the origins. I also discuss a technological development in transportation in this dissertation, which provides an opportunity to highlight some specifics of the sector. I will present the arenas of development concept through a brief reference to two case studies: the development of high definition television and the liberalisation of the electric sector in Denmark. Although these are not transportation cases, the concept of arenas of development will reveal its strengths to capture the dynamics of large interacting systems or actor-networks, adding a new level of understanding to the processes of script definition and distribution of agency which I will now introduce.

Actor Network Theory

Through analyses of the failed attempt of engineers from the powerful state company Electricité de France to introduce the electric vehicle for transport in their country during the 1970s (Callon, 1986, 1987) and attempts by another team of engineers from powerful state and private companies to design and operate the innovative public transport system Aramis in the south of Paris between 1970 and 1987 (Latour, 1996),

Callon and Latour propose some elements to consider as basis for a *realistic* analysis of design.

First, both authors agree that the point of departure is to accept that society is made of associations of humans and non-humans (Callon, 1986: 21; Latour, 2005). They propose to call these associations actor worlds or actor networks. And most importantly, these associations do not pre-exist as static categories (like family, school, company, church etc.), but are created through the activity of their constitutive elements (Callon, 1986: 24). In Callon's, Latour's and my cases, urban transport projects are proposed actor networks. What technologists actually do in these projects is to conceive, design and develop technical systems and the 'societies' or contexts in which they take place. They are in fact engineering-sociologists or heterogeneous engineers (Callon 1987: 83). Design is therefore the activity of defining sociotechnical scenarios (Callon and Law, 1988: 285, 287).

Callon characterizes the process of design as co-evolution (1986: 20, 33). This implies that when technologies produce a new actor network, they engage in tasks of undoing connections and establishing new ones (Callon 1987: 96). The actors that take responsibility for the project engage in specific activities of simplifying and juxtaposing other entities or actors (Callon 1986: 30) – finding spokespersons for all the elements they want to mobilize for their project. Callon (1986) defines more precisely this as the activity of translating. This implies interesting other actors, defining a script for them, having them accept the script (and thus the central actor's organizing efforts), and in the end adjusting themselves to fit the project. In a detailed case study, Latour prefers to talk about chains of translation (1996: 33), which certainly better fit the scale of the type of projects we are dealing with here. In short, technologists' task is to create associations (Latour 1996: 57) through a proposed delegation of agency to the other actors involved (Latour 1996: 81; and see section 3.1).

Callon and Latour are cautious not to propose that there exists a definite set of strategies actors can deploy to advance their projects. In their case studies, however, they present some strategies actors actually deployed: reaching out for the market (Callon, 1987), although market forces should be considered actors (Latour, 1996: 41); problematization (Callon 1986: 26), which should be understood as the careful definition of a problem or set of problems in order to produce certain translations; and finally contextualization (Latour 1996:142-155), which is when technologists carefully match the project's features and a proposed context of use, thus ensuring success; conversely, failure is the consequence of de-contextualization of the project, of not being able to produce the object and its scenario.

Callon and Latour carefully avoid explaining success or failure by totalizing concepts or events outside the reach of the actors (Callon and Law, 1988: 284), and they rule out any "fatal flaw" type of explanation (Veryard, 1997). This is what is called the principle of agnosticism about success and failure (Latour 1996: ix). They also carefully recreate analytically the uncertainties designers face at the time they are making decisions (Callon, 1986: 24; Callon, 1987:87; Latour, 1996: 19, 66), in order to avoid projecting, from the past, the future fate of the project and thus incurring a circular rationalization of the failure of their projects (Law, 2004). Failure and success depend on the strength

of the associations of the involved actors in time. Therefore, a project is a success at some points in time, and a failure at others Vel (the electric vehicle) is a success in 1973 and a failure in 1976; similarly, Aramis is a success in 1973, but in 1989 its network of support is completely diluted: then, it is a failure.

All the elements and conceptual vocabulary presented above account for what Latour calls the "whirlwind model of innovation" (1996: 118): an open model that invites to account for the multiple and heterogeneous sociotechnical strategies that actors deploy to produce a working transportation system. In this sense, this model is more robust than the much criticized normative linear model of innovation. However, the critique has to be repeated, because it is still the case that the linear model is put forth as the model for innovation (Brand, 2008: 134). This model matches the rational model of planning: the four-step model (Valderrama and Jørgensen, 2008: 215).

Actor-Network theory as initially presented in these case studies has been much criticized for its "managerialistic" approach (de Laet and Mol, 2000; Winner, 1993). However, the principles and concepts have indeed made career in many fields, such as innovation studies (Akrich, Callon and Latour, 2002, 2002a), urban studies (Farias and Bender, 2009; Graham and Marvin, 2001), architecture (Latour and Yaneva, 2008), social sciences (Law, 2004) and information management (Monteiro, 2000). The analytical approach and vocabulary of ANT is still worthy for my study, as I focus on the core designing team or planner team of Metro and Transmilenio; However, some qualifications must be made to Callon's and Latour's cases in order to understand the limitations of their approach. Although they claim that no hierarchy should be made between the actors beforehand (Callon, 1986: 23, 25; Callon and Law, 1988: 292), their analytical selection does privilege and construct a central actor, a choice that should be admitted up front, just as Callon himself proposes in another study (Callon, 1986a). This central actor, the one that takes responsibility for organizing the proposed actor-network, develops a protected space for action, which Callon designates as an obligatory passage point (Callon, 1986:27; Callon and Law, 1988: 289). The strategies for protecting this space should be further discussed (see the next section on LTS and 3.2 below). Focus on a central actor makes it difficult to be loyal to the principle of avoiding taking sides (Callon and Law, 1988: 285). This also has a consequence, when it is acknowledged that analytical texts tell stories and are thus narratives that also produce effects:

> If the word 'love' seems a bit romantic when dissecting the fate of a public transportation system, part of Latour's genius is to make you care about the train as much as any person involved. The book's title hits home when the reader realizes that to love technology is to fall under the spell of all the human and nonhuman actors who create it (Weistein, 1997).

As presented in these initial case studies, ANT falls short on four other counts, to which I dedicate some lines in the following paragraphs: the markets' role; actors' transformation and resistance; users' roles; and big politic's' role.

Although Callon states that technologists, unlike sociologists, are judged ultimately in the market place (1987: 90), this is hardly true for urban transport projects like Aramis, Transmilenio and Metro. These types of projects struggle from the outset to design a

system for a captive market: they compete *for* the market, not *in* the market. If Aramis had succeeded, then the commuters of the Petit Ceinture would have little public transport choice other than Aramis; just as today, the residents of various parts of Bogotá are bound to Transmilenio as the only choice of public transport, and the dwellers in Ørestad in Copenhagen depend on the Metro.

Another weakness in these ANT analyses relates to the nature of the resistance of actors to being enrolled. Callon states that others naturally resist being enrolled (1986: 31; 1987: 91, 96), although in a footnote to one of his articles he admits that actors do not "resist stubbornly" and that "reality is not static because it consists of interstices that permit it to move, gather, alter, and divide; thus there is room to 'make'" (Callon, 1987: 102). Furthermore, his case study suggests that others resist because they have other paths of development (Renault, for instance, in Callon 1987; or the air fighter f111 in Callon and Law, 1988). However, those paths of development are not explored and thus the nature of other actors' resistance is not brought into the analysis (see section 3.3).

These initial case studies contain no treatment of users, apart from a few side notes in Callon (1986) and Latour (1996). Callon corrected this in his recent studies on muscular dystrophy, developing the notions of "concerned groups", in collaboration with one of his colleagues, Volona Rabeharisoa. They suggest that groups of concerned individuals can actually "impose a new form of articulation between scientific research and political identities by directly linking the issues of research content and results to that of their place in the collective" (Callon and Rabeharisoa, 2008: 230).

Big politics are also absent from the analytical framework, although they are present in the case description (Callon and Law, 1988: 293-4). The fact that urban transport projects happen in cities where there are institutional structures of power and administration, and where companies normally staff their working groups strategically with people that can navigate through city politics and the municipal bureaucracies is a key element that should not be overlooked (see LTS below).

Finally, what in the end explains failure and success? What Latour and Callon definitively rule out is any single explanation. Instead, they suggest that each project has its own combination of multiple reasons that explain either success or failure, or temporary success or temporary failure. In the case of Aramis, Latour states that the Aramis designers had too much faith in their own invention and thus believed that the social virtues of their product were self-evident. In addition, they did not pay enough attention to the social innovations required for Aramis to become an objective reality on the streets of Paris. And finally, they had an uncompromising approach to non-material coupling as the essence of the transportation system.

One way of summarising the rich vocabulary proposed by Latour and Callon in these initial studies could be the following: the organising or central actor engages in processes of distribution or delegation of agency to the proposed elements that will constitute the new system. This process of delegation happens through translation (interessement and mobilization) of existing entities, and through the development of new entities. I will focus in my research in some of these new entities which I will characterise using another ANT concept: script.

Madeleine Akrich (1992) proposed to import from semiotics a number of concepts to analyse the process of design of objects. The concepts relate all to the root script: inscription, description, pre-inscription. A script is a proposed scenario in its wider sense. It could become a material set of characteristics or not. But in either case it becomes a constitutive element of the new object or system. Other actors and users can accept the proposed script, performing an action of pre-inscription. If they reject the proposed script they can also perform an action of *de-scription* and *re-inscription*. A new technology or system is thus constituted by a set of scripts that have been negotiated and that become relatively stabilised in time. In this dissertation I will trace the process of definition and stabilisation of some of the material scripts that compose Bogotá's Transmilenio and Copenhagen's Metro, in order to account for the processes of distribution of agency and re-configuration of the arenas of development that in turn constitute the city.

Large Technological Systems

The intellectual father of this theory of technological change and knowledge development is Thomas Hughes. Trained in Electrical Engineering, Hughes took up history in his graduate education and became one of the most respected historians of technology in the United States and Europe. Through a massive and very detailed study of the history of electricity in the United States, the United Kingdom and Germany, Hughes (1983) developed some concepts to account for the many ways in which technical decisions are simultaneously political. The main concepts I want to refer to here are "system", "system builder" and "reverse salient". For Hughes, the unit of study should be the system, understood very broadly and loosely as related technical components, institutions and individuals. Within this set of elements, those that define the objectives of the system have a protagonist role and should analytically be considered the system builders. For any given system, the system builders are mainly individuals, although with big operating systems, the role can also be distributed among institutions, and even components. Reverse salients refer to situations when the system does not grow or develop as expected, but no one can explain why: it is a situation of incomplete information and confusion. When a reverse salient is rationalized it can be broken down into critical problems, the solution of which can actually change the direction of development of the system or even create whole new systems.

Many years after his initial study, Hughes developed a history of systems theory developments in the United States, concentrating on various key projects: SAGE, Atlas, CA/T and Arpanet. These studies are presented in his book *Rescuing Prometheus* (1998). His analysis of the design of the Central Artery and Tunnel (CA/T) in Boston is of particular interest for this dissertation, because it was an infrastructure project for transport in a city.

For Hughes, "CA/T becomes congealed politics" (1998: 1). This means that the very structure of the project and its elements results from interaction among social groups that influence the project. It is the outcome of the dynamic power balance of these groups that define technical features. Unlike ANT theorists, Hughes is less concerned in developing concepts to account for these processes, and more interested in describing

them in historical terms. Hughes notes that with the CA/T, there was no possibility of isolating the project, as in the military projects SAGE and Atlas (1998: 2). Therefore, politics, and especially urban politics, shape the project and render much of the knowledge in systems theory, developed for the military, useless in the CA/T case, unless it is modified.

The whole CA/T was about literally undoing previous connections and establishing new ones, which in the long run accounts for one of the major city renewal projects in the history of the United States (1998: 2). Through CA/T, Hughes also accounts for the way big urban projects bring resources to the city (1998: 5), and how that process shapes the project itself, because projects often have to accommodate demands from those who decide about resources: i.e. politicians at the national level (1998: 9). Hughes emphasizes once more the role of the system builder and the key role of such a character. By showing how projects are sometimes people, he also suggests that people are sometimes projects (1998: 10)[1].

Other elements worth mentioning are: First, how bringing in distant projects as arguments shape the project – previous experiences of contractors, similar projects in other parts of the world or alternatives that have proven problematic elsewhere (1998: 11). Second, Hughes describes how the process of definition of the public institutional agency in charge of the project is an especially delicate decision. In Boston, Fred Salvucci – the main system builder of CA/T – decided for a weak public works agency in order to strengthen and protect the project (1998: 13). A similar move was made in both Bogotá and Copenhagen, where whole new institutions where developed to take care of the projects (see section 3.2). Third, the Environmental Impact Statement functioned in the CA/T case as one of the most powerful inscriptions: an organizing document endowed with legal and managerial authority played a major role in the project (1998: 16). This document had also a powerful impact on city development (1998: 17). Fourth, the CA/T case shows how one element – in this case the Charles River crossing – can focus attention and inherit all the bad publicity of a project (1998: 18, 22), which shows the importance of accounting for certain scripts (see section 3.1). Fifth, the strategy defined to solve a given problem can determine its outcome. This was the case when Salvucci's plan Z for the design of a crossing over the Charles River was submitted for consideration by a committee appointed by the new administration. The composition of the committee clearly implied that plan Z had no chance. Therefore, discussing the strategy *is* discussing the design at many stages during the project (1998: 28). Finally, Hughes emphasizes that meetings are the knowledge building scenarios par excellence in this type of project (1998: 32). Not only technical reports and raw data have the status of knowledge, but meetings' records as well, because it is there that knowledge enters into action and decisions take shape.

[1] In my cases, it is difficult not to note how Enrique Peñalosa's involvement with Transmilenio makes the whole system part of his identity, or in Copenhagen's case, how Anne Grethe Foss' central role in the Metro from conception to date make the project and its technology much more than just a job or a technical project she is working on. Put in other terms, if called on to provide advice on a transport problem in any city in the world, the chances are high that Mr. Peñalosa would recommend a BRT and Mrs. Foss an automatic metro system. Similarly, Latour, Callon and Law would very likely recommend ANT analyses and Hughes LTS analyses for the development of science and technology studies research projects.

In Hughes' analysis of CA/T, users have a more central role than in his previous work and the ANT cases described above. Throughout his detailed CA/T case study, Hughes shows how neighbourhood associations, professional associations, different ethnic, social and other interest groups in Boston, commentators, experts and many more influence the design. As Secretary of Transport of Boston, and as a person interested in interaction and in developing a project that benefited the majority, Fred Salvucci interacted with these heterogeneous groups of users and changed the design of CA/T in many instances. In the case of Plan Z, a good many social groups aligned themselves against Salvucci's solution for the the Charles River crossing, so it is not the rosy picture of interacting for a better project that we find here, but what Hughes calls the "messy complexity". According to Hughes, messy complexity *is* politics (1998: 34).

The LTS tradition has produced a rich description of many transformations of large systems around the world (Coutard, 1999; Hughes and Mayntz, 1988; Summerton, 1994). The *polysemy* of the word system has been a strength in the tradition (Beckman, 1994; Offner, 1999), providing with an inclusive concept that brings together histories and analyses of diverse technological networks with a focus in the sociotechnical dynamics that constitute them, rather than in quantitative measures of performance or coherence. A volume edited by Jane Summerton (1994) showed several cases of change in large technological systems, that revealed how the "periods of stability in technical systems and networks are typically only provisional" (Summerton, 1994: 5) and how change implies dynamics where "*previously achieved closure is undone*" (Summerton, 1994: 5 emphasis in the original). This tradition also emphasises the role of system builders and their changing character through the life of a system, and the role of big politics in the whole process (Summerton, 1994: 14). These elements I take for my analyses to further argue that the production of a technological system, like an urban transport system, entails the reconfiguration of its environment and thus of a space populated by several systems or actor-networks that interact in competitive as well as contributory ways. That space I characterise as an arena of development, and thus I now turn to defining such a concept.

Arenas of Development

In two of the papers included in this dissertation, my supervisor and I made a basic introduction to the concept of arenas of development (Valderrama and Jørgensen, 2008: 208-209; Valderrama, 2009: 132-133). In the following paragraphs, I provide a more detailed presentation of the concept in order to justify its selection and explain the way it complements the tools of ANT and LTS.

In their study of the development of high definition television (HDTV) in Japan, Europe and the United States, Jørgensen and Strunge (2002) focused on four questions: First, what is the nature of the locations and spaces for innovation and technological change that have to be managed? Second, for any given innovation or technological change, how can designers map the field? Third, what relations need to be de-structured? And finally, how do those processes enable change or innovation?

They state that space is not related to geographical locations, but refers more generally to a "meeting environment" where actions can take place – documents, tele-

conferences, conferences, meetings, public announcements, rumours etc. In contrast to space, location does refer to a specific geographical and physical place. Technological change and innovations involve a number of very dissimilar processes held together by various linkages and interdependencies. They distinguish three such families of elements: actors, artifacts and standards; locations; and translations (in the ANT sense). An arena of development, say of HDTV, exists in relation to specific locations in the world and to specific situations. More concretely, it can be defined as a "mental space for a discussion that focuses on the relational, unstable and heterogeneous character of development processes" (Jørgensen and Sørensen, 2002: 199). Like ANT, arenas of development theory emphasizes the development process rather than the finished or stabilized entity.

The metaphor of arenas of development relates loosely to the image of a circus arena, but one were performances related to specific sociotechnical problems take place. It resembles the idea of "patchwork" of technology stories, and it uses the idea of partial connections and multiple stories. It specifically addresses conflicting interests, and contentions about the nature of the space itself. The performances depend both on actors and audience (users of various kinds). In this manner, the development arena concept allows visualizing the heterogeneous elements that compete for attention and power in the arena. For any given process of production of a technology (HDTV, for instance) or system (such as Metro or Transmilenio), the concept of arenas of development enables a decentring of the object of study from the finished or proposed artefact to the vexed and contingent process of inscription and delegation of agency – i.e. to the processes of becoming, shaping and structuring. Arenas of development shift the focus from one laboratory (or designing team) to the interaction of various laboratories (or possible contributors to the design or planning process). More precisely:

> "a development arena is a visualising spatial expression of processes of competition and co-operation. It should convey the idea that several actor-worlds are being construed within the same problem area. It depicts the idea that several actor-networks co-exist and interfere with each other within a certain problem space." (Jørgensen and Sørensen, 2002: 208)

Following the development arena of HDTV, the authors propose a series of strategies that different actors can deploy to develop their solution. I present some of the proposed strategies in a short summary of the case. HDTV was born in project MUSE in Japan, where a team of designers wanted to transform the existing television system of the country to improve the quality of images. They adopted a *strategy of resettling and inclusion* to advance their project. Europeans reacted to this first move establishing first a strong network of industry giants and operators to design an artefact that would secure their power position: it was a *strategy of extension and differentiation.* The United States came into the arena last, moving from the audience to the main scenario. The main sites of development are technological laboratories not tied to industry interests, which quickly propose a change in standards from analogue to digital technology. This move reconfigures completely the arena, pushing the Europeans and the Japanese from the centre to the margins: this was a *strategy of exclusion.* Until that point, the arena had been dominated by a struggle to define the standard to use for the new developments, but then a design team in Scandinavia developed a working high-definition digital television set, tilted the balance definitely in favour of digital technology, and moved

the emphasis from the standard to the working devices themselves: this was a *strategy of re-framing*. A conglomerate of media technology giants like Phillips and Sony entered the arena at a later stage. Despite their histories of past successes (and also failures), they were unable to colonize the arena, where other actors already held a strong position, so they decided on a *strategy of multiple engagements* that did not favour one actor but negotiated with various actors. At this stage, HDTV remained a highly contested standard and technology. Although Jørgensen and Sørensen do not fully develop the next phase, they note that progressively the negotiations among actors (which involve movements between multiple locations and the assembly of new locations) produced a more or less unified standard and technologies. This last strategy can be described as a *strategy of reduction and ordering*.

This brief description of a complicated process provides a taste of how the arenas of development concept helps to account for the development of HDTV: From being a more or less diffuse proposal for the improvement and transformation of Japan's television, it becomes a worldwide struggle about standards; soon afterwards the development of working devices in Scandinavia re-centres the focus on the whole television system; and finally the diversity of possibilities gives way to a more or less defined trajectory of high definition *digital* television.

In their study of the process of liberalization of the power supply in Denmark, Jørgensen and Strunge (2002) focus on how technological and environmental options are constructed and translated throughout a radical re-configuration of the supply sector. More concretely, they investigate two aspects: first, the distribution of property rights and the institutional structure and how they change; and second, what potential there is for regulating the sector, given the proposed transformations. The authors claim that "the creation of policy objects and the enrolment of certain rationales in policy discourses are thus important steps in the policy formation process in a [given] arena [of development]" (Jørgensen and Strunge, 2002: 299). They describe, for instance, how an energy crisis in Denmark, coupled with the emergence of renewable wind energy devices for production of electricity, reconfigured an arena in which production had previously been highly concentrated in a few companies. Therefore, at least two actor-networks can be differentiated: public utilities using traditional methods, and renewable private suppliers with some support from the government. While the first had dominated for decades, the emergence of the second entailed a change for the whole arena and thus for both actor-networks. It is in this state of affairs that the European Union presented its directive for the liberalization of the power supply. The article also shows how agencies and institutions more oriented toward activities in open markets (like the federation of industries or the competition agency) suddenly become empowered, while institutions favoured by traditional regulation were weakened in an arena of development where the government initiates liberalization processes. Another interesting aspect is the role of users: governments assume that the end user wants first and foremost to pay less for energy, which is supported by economic theories that claim that delegating agency to market forces benefits first and foremost the end user, since low prices become possible as a result of more efficient production. However, the Danish cases presented by the authors demonstrate that not all users (members of communities and grassroots activists) want that. They would rather retain influence – for instance to pressure for the adoption of environmentally friendly technologies – on

publicly regulated power suppliers at the expense of promised reduced service prices (2002: 310).

In a nutshell, Jørgensen and Strunge apply the concept of arena of development to understand how the energy supply sector in Denmark evolves in time, and how actors, institutions and their relations change with the entrance and growth of new technologies and especially through a major policy change steered by the European Union and the Danish government. The concept of arenas of development enhances an analysis where multiple systems, rationales, and actor-networks compete, interact, and interfere with each other, changing in time, and re-shaping the whole arena. Notable in this analysis is the role of multiple users.

The concept of arenas of development adds three important elements to the framework of ANT and LTS. First, it helps visualize the process of creation of a new system or actor-network in relation to other existing systems or actor-networks. In the case of urban transportation, this is relevant because cities are spaces where there already exists an established order that is going to be destabilized and changed by the new system. Secondly, in the case of urban transportation, these systems that populate the arena of development have an institutional and technological core that plays a powerful role in their identities: bikes, cars, trains, buses. Note that the arena of development is not a space that contains the actor-networks or systems but a conceptual space that is defined by the actor-networks' interactions. Therefore, as I show in this study, affecting one of the systems or creating a new player entails affecting the arena as a whole. Finally, the arena of development is a space defined by the performance of the transformations. Therefore, the arena of development is not a static space. This idea supports the conceptualization of innovations as the undoing of connections and the establishment of new connections, rather than a process of only addition of new materialities, new institutions, new devices and new knowledge.

ANT, LTS and arenas of development are useful because they provide an initial set of concepts that respect the principles of agnosticism (taking no sides), generalized symmetry (accounting for actors' roles in the same terms), and multiple associations (abandoning *a priori* distinctions between the technical and the social) (Callon, 1986). I particularly refer to Transmilenio and Metro as both systems in Hughes' sense and actor-networks. I focus my analysis on tracing the development of certain scripts to unveil the processes by which the designers distribute agency to different parts of these systems and how that process implicates a re-organization of the arena of development of transport.

3. The Design of Large Technological Systems

3.1 Scripts and delegation of agency in an arena of development

In this chapter, I further explain the elements that comprise the answer I have developed through several years of research to the question of this dissertation. (Before presenting the answer, please note that many of the elements that compose the answer have been developed in the articles in the appendix. The reader may choose to go to the articles when they are flagged, or read the articles before reading the whole of chapter three). To the question – How do designers conceive and define the main features of urban transportation systems? – I answer by summarizing my findings as follows:

> Designers discuss and define *scripts* that make up the transport system and the city. During the process of definition, designers make readings of the history of transport's *arena of development* and *distribute agency* to the defined elements in order to make it work and make it stable in time. The defined elements are a in a state of precarious stabilization that relates to the humans and non-humans that compose the *system*. During the process, the actors involved change, including the designer actor. Current and future users also play a role in the process in the form of real or represented users or concerned groups. Because of the scale and character of transport systems like those considered here, the process of definition of specific *scripts* entails a dynamic of undoing established connections and proposing new ones in the *arena of development*. The nature and extent of the connections are such that the whole process involves a transformation of the city.

Scripts, delegation of agency and arenas of development

In "The co-production of transport systems and the city" (Valderrama, 2009: 126-127) and in section 2.3 of this dissertation, I present a discussion on the concepts of script, inscription, description and pre-inscription, which also belong to ANT and enrich the vocabularies proposed to account for the processes of knowledge production and technology development. Let me add here just three supplementary comments regarding Akrich's concepts described in that article: First, users' role in Akrich's analysis is only reactive, as they can either accept (pre-inscribe) or reject (de-scribe) the proposed scenario (Summerton, 2004: 488; Oushdoorn and Pinch, 2003: 9; see section 3.4 below). Second, Akrich's examples separate the context of design from the context of use. Because the designers of urban transport systems are embedded in the cities in which they intervene, they deal with the context on a first-hand basis (Valderrama, 2009: 127). Third, analysing scripts that actually took shape and are working scripts makes it possible to complete the ANT analysis that fell short in both Latour's and Callon's cases, since they focused on failed technologies. Thus, their cases did not reach the stage when scripts become working material scripts that further influenced the fate of the systems they constitute. Therefore, I not only account for how scripts' shape and identities are the result of interaction, but how the scripts themselves also become

actors, and how they sometimes contribute and sometimes disrupt other scripts and/or further developments of the system.

ANT and much STS literature emphasize the contingency of technologies and knowledge. That is, they are the result of conflict. But once relatively stabilized, they also become actors. Therefore, the processes of translation that ANT considers are also processes of delegating agency to various elements (Latour, 1996, Law, 2001, Harbers, 2005). In other words, when designers define scripts, they assign causes, responsibilities and agency to the defined elements. The defined scripts will work in favour or against the projected technology, depending on their stability or, in other words, their relationship to other elements or actors: their character is defined both by the elements that compose it – simplification – and in relationship to other elements of the system – juxtaposition – (Callon, 1987). Scripts refer not only to physical elements like platforms, stations, trains, but also to human operators, managers, maintenance personnel, passengers, and institutions.

In the case of an urban transport system, the scripts that compose the system and to which agencies have been distributed also play an important role in the whole arena of development. This role is twofold: First, the scripts are defined by designers based on a reading of the arena of development, its history, its state or perceived state, and how they visualize the future. Second, the defined scripts constitute the new system and also the arena of development. In the following, I present the process of definition of one script of the overground Metro stations in Copenhagen: whether they should have been closed or open stations. This case is particularly illustrative of this process inasmuch as the design decision had implications for other parts of the system, most importantly the technologies used to guarantee safe operation.

Copenhagen's Overground Metro Stations

From the very beginning of the design process of the Copenhagen Metro, architects and engineers collaborated (Foss, 1996); the system designers began to define the architecture of the system. One important element in this process was the architecture of the stations. This was due to the fact that it had been decided already in 1995 that the technology to be used would be a driverless automatic Metro (COWIconsult, 1995). Therefore, the stations' architecture had to match all the safety requirements that full automation entailed. One such requirement was to guarantee that the train could detect if anything or anybody was on the tracks and stop. By 1996, designers had already decided that in the underground stations they would use sliding doors to isolate the tracks. This decision had two technical advantages: it prevented anything from falling in front of the train when approaching the platform, and it allowed for the management of air fluxes in the tunnels in case of emergency, especially if a fire should start in the tunnels.

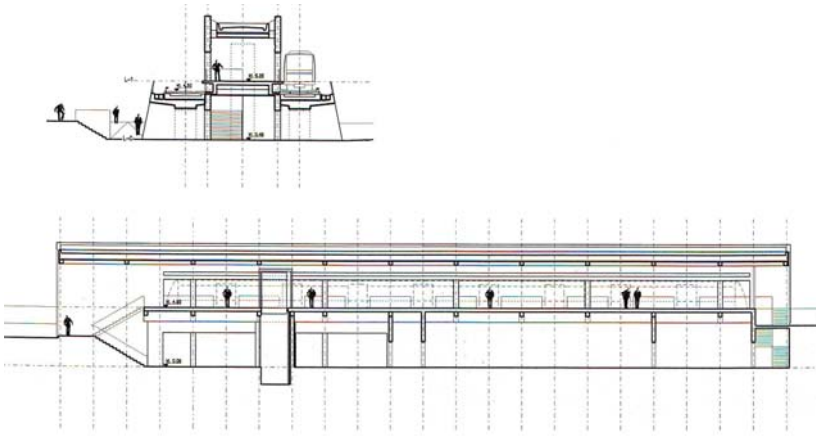

Figure 6: Drawings of a proposed design for the overground Metro stations (Sørensen and Juul-Sørensen, 1996: 20)

However, the Metro was also to have overground stations (13 out of 22). The initial proposals in 1996 projected that from an architectonic and safety point of view these stations should have a design similar to that of the underground stations (Sørensen and Juul-Sørensen, 1996: 18). Therefore, designers considered closed overground stations with sliding doors to isolate the platform from the tracks (Figures 6 and 7).

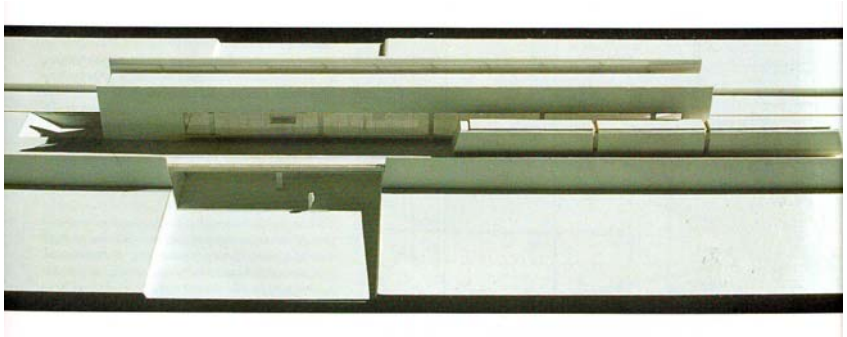

Figure 7: Picture of a model of the proposed overground Metro station (Sørensen and Juul-Sørensen, 1996: 20)

Soon after, the core designing or planning team of the Metro at Ørestad's Consortium began the tendering process for the construction of the infrastructure of the system. According to Anne Grethe Foss, the head of the Metro planning team, in the tendering terms, the designers opened for suggestions on how to improve the design of the infrastructure. The reason for this was to provide an opportunity to take advantage of knowledge that the tendering firms might have that could supplement what the designing team knew at the time. The winning firm, Comet, proposed a different design for the oveground stations, which changed the script from closed to open stations (see Figure 8). This entailed the use of a different safety system for the tracks. They proposed the use of an object detection system (ODS), which is an infrared sensor system that can detect anything or anybody that might fall onto the tracks and alert the automatic train control system (Frederiksen, 2000). Because Comet's overall proposal obtained the highest score in the tendering process, they were given the contract to

construct the overground stations. It was also the cheapest way of constructing these stations, but according to Anne Grethe Foss this was not the main reason for the choice.

Figure 8: Picture of the actual design of most of the overground Metro stations. The photograph shows Sundby Station. (taken by the author).

The change in the script from closed to open overground stations has proven to be a vexed choice. On one hand, the fact that the stations were cheaper was no doubt appreciated by the designers that had to cope with the usual increase in costs of big infrastructure projects.[2] And from the point of view of safety, the ODS has worked perfectly; no incidents or accidents have occurred during the now more than eight years of Metro operation.[3] On the other hand, the open stations only operate with the ODS, and as Anne Grethe Foss herself acknowledges, this system has proven to be an operation headache. The ODS is too sensitive, so on countless occasions operation has been interrupted by newspapers blown into the tracks by the wind, by big birds, or as one commentator suggested, even by sunlight (Valderrama and Jørgensen, 2008: 207; Marfelt, 2002).[4]

In summary, the Metro designers changed the script from closed to open overground stations through a tendering process where they opened for suggestions from the tendering companies and accepted one of them. The open overground station script could only work if the ODS script was also accepted. Safety and operation agency was assigned to the ODS. However, as is often the case for many other scripts, this script turned out to produce unforeseen problems for Metro operation, although it performed quite well in relation to safety. The open station script did not produce consequences for the arena of development as clearly as other scripts, but it certainly had consequences for the way the city is configured. From an architectonic point of view, instead of

[2] In the case of the Metro, the cost escalation was 157% over the initial estimate, while the demand shortfall was 40-45% (Flyvbjerg, 2007)

[3] As a user, I also appreciate the design on those rare occasions when the temperature in Copenhagen is high. I enjoy an open station more, since a closed station made of glass – like the one at the airport – works like a greenhouse.

[4] At the time of writing these lines (February 2010), temperatures in Copenhagen have been below zero degrees for several weeks. When the wind blows, as it usually does in this city, the chilling effect can reinforce the temperature effect making it feel like minus 10°C or even less. From a user point of view, it is most uncomfortable to wait in an open overground station for the train to come, even if it is for just 3 or 6 minutes.

relatively heavy structures that interrupt the visual line, open stations fit better into the landscape and fulfil the expectations architects had back in 1996 to a higher degree than closed stations (Sørensen and Juul-Sørensen, 1996).

Scripts analysed

In the course of this research project, I have analysed a number of scripts in relation to the way delegation of agency was discussed and performed and the role of the arena of development and the city in the whole process. I have focused on key scripts that configure the new systems, both Transmilenio and Metro, as distinct technological actors or as systems in the arena of development of their respective cities. The choice of the first script in each case (engines in Transmilenio; technological choice in Metro) was guided by the available documentation. The further choices were based on what the interviewees considered the most salient and important features of the systems they contributed to design.

The first script I examined in the case of Transmilenio was the selection of the bus engine and the fuel for the buses (Valderrama and Beltran, 2007). Although the article I wrote did not use the framework developed for this dissertation, it adheres to the principles of agnosticism, generalized symmetry and free association. The article shows that the choice of the engine and the type of fuel was a controversial issue among many actors. Heterogeneity of knowledge was also at stake in relation to diesel engines and CNG engines, in relation to which type of engine pollutes more or less and under what conditions, about operating fleets under local conditions, about the quality of maintenance, environmental considerations and so on. In the definition of the engine script other non-human actors also played a part, for instance the device for cleaning exhaust gases – a catalytic converter or a particle trap. But what is most evident in this work is how the discussion about the technical configuration of the engine *is* a discussion about who takes responsibility for the operation of the engine, for the quality of the fuel, for the pollution, for the mobility of the city, for the costs of investment and operation and so on. The end result was that through a contractual agreement the city gave the private operators (owners of the buses) the freedom to choose between diesel and CNG, demanding that they comply with an operation target. The designers, representing the city, also established a number of rather contradictory or partial demands for environmental performance: engines should be new and comply with the Euro 2 standard, even though they would be operating on low quality fuel. This paper also reveals how the discussion of the engine is also a discussion about the network for providing fuel and about air quality in Bogotá, both key aspects of what the city is.

In “Urban transport systems and STS” (Valderrama and Jørgensen, 2008), my supervisor and I elaborated a first approach to the theoretical framework of this dissertation, linking the ANT concept of delegation of agency with the LTS notion of system and with the arenas of development concept. We examined the definition of four scripts: the high platform and the traffic layout for Transmilenio; the automated trains and the traffic layout for the Metro. The point of this paper was that designers struggle to delegate agency to a number of elements (scripts) of the new system, also in order to intervene in the arena of development of transport in the city as a whole. In other words, establishing continuities and differences with what was already there in the arena of

development of transport is one of the major issues of the design task. Therefore, choosing an automatic train with high frequency and smaller size (compared with S-trains) is a way of redesigning the whole trajectory of development of the arena of transport in Copenhagen. Actually, as I discuss further in section 3.5, it *is* redesigning Copenhagen.

In "The co-production of transport systems and the city" (Valderrama, 2009), I further elaborate on the ways in which the definition of scripts is linked to the re-configuration of the arena of development, basing this elaboration on the case of Transmilenio in Bogotá. I focus on four scripts – high platform, bus design, stations in the median, and dedicated lanes – to explain how these features shape the new system and the arena, establishing a powerful boundary between the new and the existing. The main point of the paper is that designers perform two parallel processes when defining a script: one is that they engage in negotiations among themselves and other actors to actually define the script; and the other is that they read the history (past, present and future) of the arena of development in their interactions. Two comments are important to supplement the argument presented in the article. First, the reading of the evolution of the arena of development is based on the interviewees' versions. This is not a layer of explanation I add to the analysis, but something that reflects the types of reasoning and strategies deployed by the designers in making decisions. In the case of Bogotá, for instance, where a metro project has always been on the drawing board and a powerful political device – it is still true that voters prefer whoever promises to build a metro for Bogotá – it is interesting to see how the designers, and in this case with the skilful participation of Mayor Peñalosa, used its existence as a strategy to acquire the resources to develop Transmilenio. I invoke this detail in order to emphasize that an arena of development of transport is populated by different actor-networks or systems, the boundaries of which are not defined and whose interactions are heterogeneous.

In "Accessibility in urban transportation systems: an STS approach" (Valderrama, forthcoming), I investigate the definition of some scripts that constitute accessibility to the Transmilenio system. I pay particular attention to the aspects to which designers delegated responsibility for granting people in wheelchairs access to the system. I show how the process was contingent: some features were implemented in parts of the system, but not in the whole. Representatives of a concerned group (of wheelchair users) influenced the design, but only after appealing to a legal instrument called *tutela*, which grants legal and political opportunities to individuals. During the discussion of this legal action, the system builders of Transmilenio deployed financial and economic arguments to justify the lack of access to feeder lines, but their arguments fell short when attempting to explain why accessibility was possible in other parts of the system. In a way, the scripts that made the system accessible in the trunk lines forced the Transmilenio officials to admit that accessibility to the feeder lines was also possible. This also revealed Transmilenio S.A. as the first *mobilizable* transportation agency in the arena of development for transport in Bogotá.

In "The Map of Transmilenio" (Valderrama, forthcoming a), I deal with the design of the map of Transmilenio. The map is of special interest because it aims to represent the whole system in order to facilitate users' navigation. Three groups of actors met and struggled to influence the character, principles and final outline of the map: the

Transmilenio operations experts, who wanted to maximize the technical performance of the system as a whole; the communications experts of Transmilenio and their supporting consulting staff at Steer Davies and Gleeve in London, who had particular views of the users based on a whole body of knowledge on signage; and the users themselves, who participated in various ways. The analysis of the design of this document reveals how users actually struggle to influence the design of the whole system, and how the system builders of Transmilenio deal with these efforts. Additionally, the new map of Transmilenio became the first working map to populate the arena of development for transport in Bogotá.

Together, the articles underscore the argument concerning how designers define scripts, which I summarized at the beginning of this chapter. They also show how the process also involves distribution of agency, causes and responsibilities to different parts of the new system. Designers thus act in response to readings of the past, present and future state of the arena of development for transport and the city as a whole. In this sense, the whole process is a process of co-evolution (Callon, 1986): a process of undoing established connections, and establishing new ones. The process has also been termed co-production (Harbers, 2005; Jasanoff, 2006) and co-construction (Sismondo, 2004). Although these concepts all draw on different case studies and sub-groups of STS scholars, they all share the principle that technology and society influence each other (Brand, 2008).

The character and size of the aforementioned intervention was possible because a group of designers or planners was able to act. In the course of my research, I found that they were able to act, because they had developed a protected space for the accumulation of knowledge and power. In section 3.2, I discuss this particular element, invoking Marques' concept of extended laboratory (Marques, 2003). As mentioned before, designers intervened in the arena of development where other systems were already present. What happened to them? In section 3.3, I develop some elements of what I call the missing symmetry of symmetrical analysis, namely the fate of the other systems. In section 3.4, I further elaborate on the role of users, and in section 3.5, I refer the discussion about how the design of a new transport system entails co-evolution with the city.

3.2 Extended laboratories

The development of both systems considered in this dissertation was organized from carefully designed institutions: Transmilenio S.A. for the system in Bogotá and Ørestadsselskabet or Ørestad's Consortium for the system in Copenhagen. Why were the systems not developed by established institutions? Why create new institutions? What was the character of these institutions? How did they operate?

These questions are relevant because in all the projects considered and referred to in this dissertation (Transmilenio, Metro, Aramis, Vel, Ca/T), a core group of designers is attempting to create a system and thus to re-organize the cities and the worlds in which the cities exist. Although ANT assumes that no actor is more important than the others, my observations show that this is not so; in fact, there is a central actor. It is important to note here that ANT insists that there is no central actor *beforehand*, but that it

becomes central. The theory of Large Technical Systems accepts from the outset that there exists such a central organizing actor, defined as a system builder, reduced in many cases to one person.

The concept of arena of development suggests that there are several central actors attempting to sustain their participation and thus occasionally engaging with other powerful central actors from other systems or actor networks that populate the arena. It is this interaction between a proposed new system and the existing systems or actor-networks that Marques (2003) has also studied. He states that in order for the new actor or system to have any chance in front of what already exists, a good deal of legal work is performed. Thus, a central actor is not only an actor with competencies in engineering, finance and management, but often its strength or capacity also lies in powerful and stable relations with banks and/or lawyers' offices. These lawyers are often recruited to study the legal topology of the arena of development and to propose ways of re-interpreting the law to benefit the new system. In what follows, I present the findings in the cases of Copenhagen and Bogotá that further develop these ideas.

Copenhagen

The Copenhagen Metro was born with the participation by staff from Danske Statsbaner DSB (Danish State Railways), although that same company had other plans. In fact, since the 1950s, DSB had established a plan of expansion for the greater Copenhagen area that included a connection to the airport through the more populated areas of Amager (see figure 9). During the 1980s, there were some preliminary design developments defining the route, stations, and size of the tunnel for the S-train to the airport (see figures 9, 10). However, DSB was a big state-owned company, and there were many other projects of expansion in circulation from many of its staff members. According to Jens Rørbech, former city engineer in Copenhagen and an active member of the Würtzen committee (see below), another such plan consisted in covering the wide track areas to the south of the Central Station in order to construct high-rise buildings with trains circulating underneath.

Among the variety of projects that circulated at the time, one succeeded in moving from the drawing board and into the political discussions in the city council and the Danish parliament, namely the idea of a Metro. Its proponents succeeded in establishing a political network to support the idea due to some specific reasons. According to my interviewees, the story is that at the end of the 1980s, Jens Kramer Michelsen, Major of Copenhagen, decided to change the status of the city from being the backyard of the country to becoming its locomotive. He was not alone in his concerns but could also count on the sympathy of many other politicians, including Prime Minister Poul Schlüter. Copenhagen was increasingly becoming a poor and downgraded city, because like in so many other cities in the world (Graham and Marvin, 2001), residents and businesses were moving to other parts of the country. Kramer, some city council members, and some politicians at the national level decided to establish a committee to work out some proposals. The committee, which was named the Würtzen committee after its first director, Hans Würtzen, included members of the Ministry of Finance, Ministry of Transport, staff from Copenhagen's municipality, and the head of the

planning office of DSB, who had also worked in the Ministry of Transport, Anne Grethe Foss.

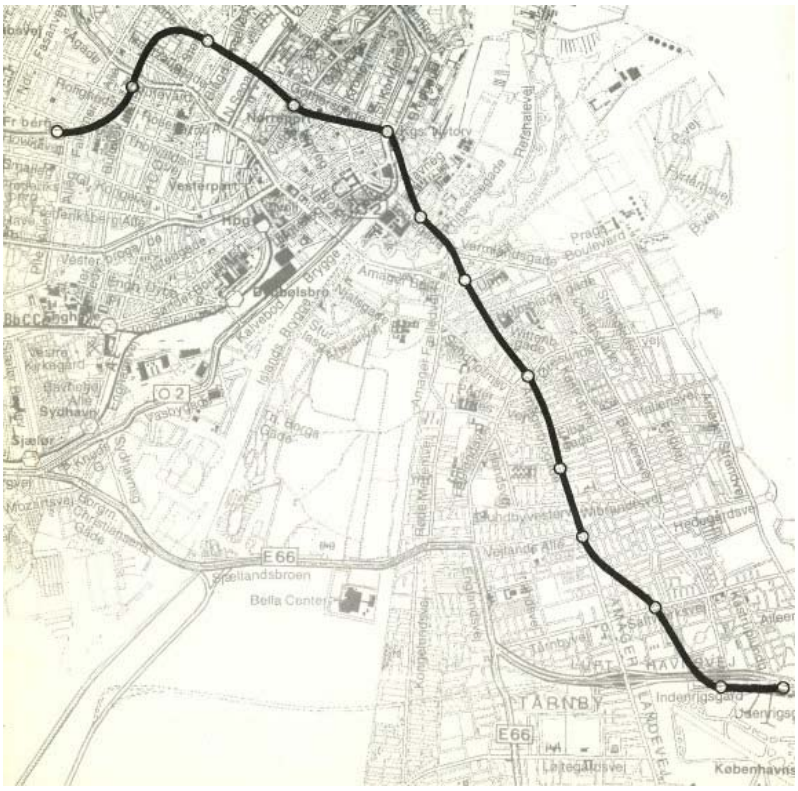

Figure 9: Proposal for the route of a S-train from Frederiksberg to central Copenhagen and further south to the airport (Trafik- og Kommunikationsministeriet, 1988: 24)

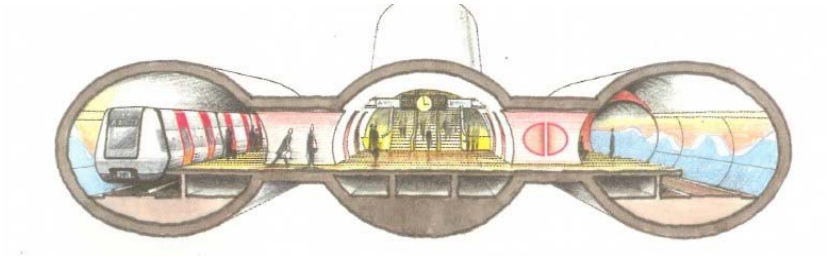

Figure 10: Drawing of the projected underground stations of a S-train running from central Copenhagen to the airport (DSB, 1988: 32)

The committee came up with a proposal to develop Copenhagen through a strategy of strong central growth and interlinkage of the city with its neighbouring centres. This meant that instead of viewing the Øresund as a border between Denmark and Sweden, they would develop a fast link over the sound with Malmö, thus making the axis Copenhagen-Malmö a competitive region in northern Europe. The Store Belt, the big bridge connecting Zealand with Funen and thus establishing a fixed link with Jutland and continental Europe was already under construction, and the upgrading of Kastrup Airport was already underway as well. So the committee proposed that the whole of Amager, which had traditionally been a low-status area, should become one of the main

focal points for investment, along with the old port areas of Copenhagen (see figure 4, page 20 above).

Politicians also determined that the development projects should not be funded by tax money but should generate their own resources. This was a highly political issue, because tax money from the national level was decided in parliament, which in Denmark is composed mainly of politicians coming from outside Copenhagen. According to Jens Rørbech, this meant that when money was allocated to Copenhagen, other regions had to be compensated. The members of the committee decided to base their proposals on the fact that the state of Denmark and the city of Copenhagen owned the ports and the land in the non-populated areas of west Amager. This undeveloped land had little value, but if a strong development project was defined for these areas, the value would increase. Selling that property for a high price would then generate the resources to develop its own infrastructure, without using taxpayers' money from elsewhere in the country. This framework had consequences for the alignment of the proposed transport infrastructure, as it had to serve mainly the areas where future construction was to take place, and not the areas where people were already living in Amager (Valderrama and Jørgensen, 2008).

It is worth noting that in this case the financing scheme was different from those used previously to improve and extend the S-train network, and also that DSB was a state company responsible for train infrastructure, service and operation all over the country. This meant that politicians considered it appropriate to take the project away from DSB and create a new institution to develop it. The new institution, Ørestad Consortium, was owned by the state of Denmark (45%) and the city of Copenhagen (55%). The percentages also reflected the proportions of property ownership of the lands allocated to the development project. According to Jens Rørbech, however, the character and management style of the company became that of a private company, not a public institution. This guaranteed a certain protection from the public, in order for planners or designers to steer the whole technical development of the project. The first head of the company was a manager with extensive experience in private multinationals, who soon drowned in the *messy complexity* of the project. Then, Anne Grethe Foss, who like Fred Salvucci in Boston, had long experience in public institutions, was capable of managing the project and its countless sociotechnical details.

By the time Ørestad's Consortium was established, it had still not been decided that the technology to be used was to be an automatic metro, but the S-train type of technology was already ruled out. In fact, it had already been decided that the new train or tram system would be independent from the rest of the train systems in Denmark; they would not share tracks. This explains why the proponents of the new system were not concerned about moving away from the one institution that possessed the most knowledge on train design and operation. They were endowed with the mission of doing something different, of moving away from the scripts that constitute the S-train network.

The Copenhagen case shows how the design of a new institution is closely related to the definition of certain scripts of the system (the choice of technology; the layout) and of the city (the new town development). The design of the institution is performed in the

higher closed circles of politics, in ministries and in the administration of Copenhagen. The choice of people is also critical, since system builders have to be able to cope with *messy complexity*, in the words of Hughes. Finally, the character of Ørestad's Consortium, which was run like a private company, provided the necessary protection for the designers to accumulate the new knowledge necessary for the development, and at the same time it phased out established knowledge (DSB) from which principles the designers of the new system were departing.

Bogotá

Viewed from an overall perspective, the case of Bogotá is similar to that of the Copenhagen Metro, although the specifics are different. When Enrique Peñalosa became mayor of the city in 1997, he was convinced that something had to be done to solve the locked situation of public transport in the city. At the same time, he was conscious that intervening in transport *was* intervening in the city as a whole. Peñalosa disliked the standard solution of a rail system, especially considering that Bogotá is already a very densely built city. He then set up two different teams to work in the alternatives: one for a metro; and another for a bus solution, funded by donations from the United Nations Development Plan, UNDP, fund. This meant that from the outset the planners working on the transport solutions for Bogotá were protected from the control institutions of the city and the state. This was the result of a special request by Ignacio de Guzmán, the head of the planning team, who was conscious that in order to do something new, the designing team had to be protected from any control organism.

When this team assembled the main scripts that compose Transmilenio, they proposed to the city council the creation of Transmilenio S.A. This new institution was to be independent of the Secretaría de Tránsito y Transporte - STT, which managed transport decisions in the city. The main official argument to defend this proposed institution was that new systems needed new institutions. However, my interviewees state that the new system had to be protected from the vested interests that had already captured the STT; otherwise, the new system could have been undone (Ardila-Gómez, 2004). Establishing the new agency was also coupled with one major design script: the dedicated lanes. In other words, a key element of the constitution of Transmilenio S.A. by the city council was that this insitution was going to have the right to establish and administrate dedicated lanes in the main avenues of the city for the exclusive use of Transmilenio buses.

The first designers working as the special group to design Transmilenio and the institution Transmilenio S.A. enrolled many other actors, groups and firms to produce the knowledge needed in the process of producing Transmilenio. Through normal procedures of tendering, they engaged renowned local and international consulting firms (Valderrama, 2009). They also deployed a strategy of infiltrating the current arena of development to accumulate knowledge of how the collective public transport system of Bogotá worked technically, financially, socially and, most importantly, emotionally. In fact, according to Ignacio de Guzmán, a psychologist was incorporated in the team in order to understand what different human actors felt, how they would react to changes, and what possibilities existed to mobilize them. This particular focus allowed the

designers to learn how to approach the owners of the bus companies and how to interest them in the new system (Ardila-Gómez, 2004).

One key element in the design of Transmilenio was the interpretation of rules, norms and laws. The process of design of Transmilenio entailed re-interpreting the Colombian legislation for mass transportation. In 1990, the congress had enacted a law that became known as the "metro law", by which the nation was committed to finance 70% of any metro system built in any city in the country. A lawyer himself, Ignacio de Guzmán and his team of designers invested a lot of time and effort in structuring the translation (i.e. mobilization and displacement) of the law from a commitment to a certain technology to a commitment to certain *capacities* (that is to move a certain amount of people in a given period of time). They succeeded in translating the law and convincing the nation to fund Transmilenio. As a consequence of this translation, the nation is now financing six new BRTs in different parts of the country.

Extended Laboratories

The main finding of the early STS works (i.e. Latour and Woolgar, 1986; Latour, 1983) is that laboratories do not create an isolated space to manipulate chunks of reality; on the contrary, laboratories enact a selective boundary from which to intervene in reality. Laboratories succeed only if they can bring the world into the laboratory and the laboratory into the world. Marques (2003: 10; 2005: 148-149) has modified this concept, introducing the idea of the *extended laboratory* to emphasize how legal work in courtrooms, lawyers' offices, and governmental committees are essential for engineering design. The analysis of Transmilenio and the Metro supports this idea, which further enriches the number of locations where sociotechnical knowledge comes into action to co-produce a working urban transportation system.

The processes of design of Transmilenio and the Copenhagen Metro required the existence of a protected space for the accumulation of knowledge. This protected space was guaranteed by Transmilenio S.A in Bogotá and by Ørestad's Consortium in Copenhagen. This kind of institutionalization, however, was neither the beginning nor the end of the stories, but one step, one decision, taken by the network of politicians and designers that believed in the transformation of their cities through the development of certain engineering projects. The persons that composed these agencies changed over time and the contributors to design via tendering or via political negotiations also varied in time, making these, the core groups of designers, variable in composition and in character.

Unlike Ardila-Gómez's agencies, which as mentioned previously should be capable to begin with, the story of the becoming of Transmilenio S.A. and Ørestad Consortium show that the agencies were *made* capable through careful institutional design and selection of staff. Also, the process of designing the institutions was linked to the definition of certain key scripts (selection of technology in Copenhagen; dedicated lanes in Bogotá) that composed the new system. Therefore, these agencies are central actors in the process of development of the projects. These agencies are the places where the system builders act. Part of the capacity of these institutions lies within the political

network that supports them, both at the city and national level. So institutional design is clearly a place where Big Politics influences engineering projects.

3.3 The missing symmetry in symmetrical analyses

As presented in section 2.3, there are two aspects of arenas of development that improve the outreach of ANT. The first one refers to the nature of resistance by some actors or actor networks to becoming enrolled in the proposed project, or even the nature of those that are not enrolled but are affected by the project. And the second refers to the fact that urban transport projects are conceived, designed and constructed in a space where other systems are already present. Let me stress once again that an arena of development is a metaphor to account for the interaction between existing and projected actor networks or systems – the boundaries are not defined and the interactions are multiple. Objective features like time, space and city infrastructure should be viewed as a consequence of the interaction, and not as a container.

The multiplicity of ways in which different transport systems interact can be illustrated by the case of Copenhagen, using the same evidence outlined in section 3.1. It could be stated that the Metro won over DSB's plans to develop an S-train in Amager. But it is also true that the Metro was possible thanks to DSB in two ways. On the one hand, the Metro was born in the planning office of DSB. On the other hand, the whole new town of Ørestad was also made possible in relation to the fixed link with Sweden over the Øresund, and the link with Funen and Jutland thanks to Store Belt. These two links were supported in relation to a projected increase in train and car traffic (Various Authors, 1991).

Car traffic refers to another extremely vexed actor-network or system based in private cars, public streets and huge investments in highway construction. The Metro was supposed to improve public transport in order to convince car users to shift to public transport. However, it is important to note that the Metro could not exist without a projected increase in car traffic. As stated in the so-called Würtzen report (Various Authors, 1991), the whole plan for Copenhagen included the development of several highway sections in the greater Copenhagen area in order to improve car mobility. In addition, the bridges to Sweden and to Funen were only economically viable thanks to a projected increase in car traffic.

On the basis of the above, it is necessary to extend Munch and Jørgensen's argument (2001) to state that the agency delegated to the Metro is also dependent on other actor-networks' development. Their roles were also changed by the same plans that co-produced the Metro. The multiplicity of engagements, collaborations and interferences by these systems in the arena of development is what shapes the city's future development and many unexpected outcomes. Scripts materialize the contradictions and tensions of the multitude of designers, and it is never given which of the delegated objectives the designed actor or script will interact with when juxtaposed with the many others that constitute the new system. Since the Metro began operation, it has created considerable demand by passengers but not enough. The new town of Ørestad has increased the value of land but not to the expected levels, and the construction and selling pace has been slower than expected. The Metro has improved public transport in

Copenhagen in some areas but in others it has not. The construction of a shopping mall in Ørestad, Fields (the biggest in Scandinavia!), has improved the economy of the whole development, and has created more passenger demand for the Metro. However, it has also attracted more car traffic to the area, and it has hindered the opening of shops on the streets, making Ørestaden a "beautiful, modern, futuristic, clean, *dead city*", to use Jens Rørbech's words. All this is not due to unexpected developments, but because the staging of the Metro and Ørestad as a project happened in an arena of development already populated by other actor-networks. The process of design of the Metro is the process of intervention in that arena. Deciding on particular scripts (layout; train sizes; frequencies; location of the stations; station design) *is* also an intervention in the whole arena of development.

In "The co-production of transport systems and the city" (Valderrama, 2009), I present this same type of analysis for the case of Bogotá. Transmilenio was possible thanks to the economics of collective public transport, to the un-built metro of Bogotá and the containment of private car operation. Designing Transmilenio affects the whole arena of transport, and the vexed scripts will produce future situations where the contradictions of the arena of development resurface. To the analysis presented in the article I would like to add the following remarks. The arena of development of transportation in Bogotá was slowly *colonized* during the 20th century by the *transporte public colectivo* TPC to the point that it became the only system or actor network providing public transport. The strategy of *total colonization* fired back when the streets got too clogged with buses and the prices for transportation became so high, as to make the development of the Transmilenio infrastructure and its operation without subsidies economically viable. The Metro of Bogotá, also in principle a competing technology to Transmilenio, ended up lending its identity in a surprising manner. The main supporting actors actually used the project of the Metro to negotiate with the national government financial support to create a mass transportation system. As the mathematical models that substantiated Transmilenio became discussed and validated, the designers of Transmilenio were able to translate the Metro Law of Colombia into a mass transit law, thus obtaining the resources from the nation intended for the Metro, but to pay for the infrastructure development of Transmilenio. This was a strategy of *shifting roles.* Finally the constitution of Transmilenio S.A. as a public institution with the monopoly of parts of the main roads of Bogotá made possible to discriminate traffic and thus constitute Transmilenio as a mass transit system. This was possible as part of a wider set of policies intended to reduce the amount of public space cars could use. It was a *strategy of containment* of one actor in the arena of development.

These strategies further reveal how Transmilenio exists in relation to the other systems or actor networks populating the arena of development. These constitutional elements are also scripts to which agency has been delegated in order to reshape the arena of development as a whole. Those scripts are also constitutive of the city itself as they affect not the systems and their respective users.

Within STS, one of the most important approaches to the analysis of sociotechnical systems has taken up the tools of what could be termed a symmetrical analysis in sociology. However, most of the available analyses perform an asymmetrical approach. They are symmetrical in consideration of the social and the technical; and in using the

same analytical tools to account for success and for failure. But they often place in the foreground only the efforts of the designers of the new sociotechnical system, while backgrounding or not mentioning at all the efforts of the designers or system builders of the already existing sociotechnical systems. Throughout the analysis of Transmilenio and the Metro, I have found that the new sociotechnical systems were shaped not only by the careful workings of the designers making new connections and using new technologies, but also by a careful *undoing* of established connections and a *reshaping* of connections in the city in ways that cannot be reduced to simple processes such as dismissal, replacement or displacement.

In this section I have proposed the theoretical possibility which I have rehearsed for the Copenhagen case and for the Bogotá case. However, a full deployment of the effort to account for changes in the arena of development of transport in the two cities considered here would require a bigger research project. What I am stating and illustrating with these examples is that there is a lot more to the character of actor's resistance than just a natural reluctance to be displaced. And that those elements (histories, efforts, projects, laws, reverse salients, problematizations, heterogeneous constitutions, changing identities of other actor-networks) that come into the picture when setting focus in the arena rather than the new system only –also through the narratives of the interviews– influence the process of script definition and distribution of agency of the new system *and* the arena as a whole.

3.4 Passengers, users and the design of urban transport systems

The concept of arenas of development for transport allows for a better understanding of user's roles in the design process of urban transportation systems. The main point of departure is that all sorts of users and potential users already populated the arena of development: individuals, passengers, regular users, non-users, mediators, end-users, lay users, implicated actors and a whole set of entities that are increasingly being brought into analyses of design and knowledge production (Oudshoorn and Pinch, 2005). In the case of transportation, all these actors might already have different degrees of commitment to certain actor-networks within the arena. For example, car owners are more committed to use their car as mode of transportation and commuting due to the investment costs. For them, new urban transport projects might be measured in terms of how much the new systems improve private traffic (i.e. how much they contribute to lower congestion).

Nevertheless, things are more sophisticated with users. The main point that I want to present here is that users and designers are undefined groups during the design process. They change along the way. The core group of designers, working from their extended laboratory, will increasingly have the capacity to define who is invited into the design group and who is not. With the stabilization of the designed system in time, it will become clearer who was taken into the design process, what kind of passenger was envisioned, and what kind of non-user was also defined (i.e. who was excluded).

Unfortunately, the material I have collected is not sufficient to elaborate the analysis of the Metro case in Copenhagen. However, visual inspection of the facilities allows for a few remarks on the types of users. Domesticated (Silverstone and Hirsch, 1992)

passengers do not ask for information; they move quickly in and out of the trains, feel safe in an unmanned train, and if they are in wheelchairs or have a pram and have to buy a ticket before coming into the train, they are patient enough to take the elevator twice in some stations where the ticket vending machines are on a different level than the platforms. The domestication of the passengers did not happen overnight, and intermediate steps were taken. For example, during the first months, there was in fact a steward on board every train. Elements of the system were also adapted (see figure 11): deeper stations were domesticated (Lie and Sørensen, 1996) so as to prevent drunk passengers from attempting to sit or play on the handrails and risk falling (this modification to the design was actually made after two people died from falling while playing on the handrail (Danholm, 2003)).

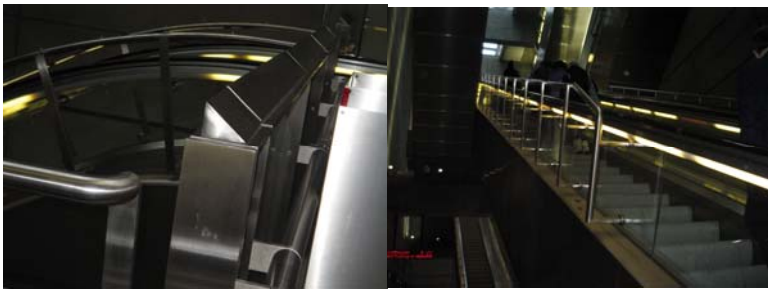

Figure 11. Pictures showing the additional devices installed to enhance the safety inside stations. To the flat veranda (left) designers added a triangular parallelepiped solid piece to prevent people from sitting in the veranda and falling into the three- storey high spaces conceived to provide air and light inside the station. To the escalators, designers added an additional rigid hand rail (right) to prevent people from playing and falling over the moving handrail of the electric escalator.
Photographs by the author.

In "Accessibility in urban transportation systems: an STS approach" (Valderrama, forthcoming), I analyse the way in which the core group of designers and planners in the Bogotá case adopted a hostile attitude towards local concerned groups, while being open for recommendations from international consulting firms. In relation to the example of Curitiba, the trunk lines of Transmilenio were designed to take into consideration the accessibility for people in wheelchairs and with prams. However, the feeder lines were not provided with the necessary scripts to enable such accessibility. Concerned groups of blind people approached the designing team to influence the design of Transmilenio, but after an initial welcome, their suggestions were not taken into account. These two concerned groups (blind people and wheelchairs users) have traditionally been marginalized by any type of infrastructure development in the city. With Transmilenio and the public space renovation since Enrique Peñalosa's administration, attention and inclusion has increased in new infrastructure development. However, concerned groups and individuals have had to use legal means to influence design, as in the case of the *tutela* imposed by Daniel Bermúdez. The design process of Transmilenio thus made it possible for two traditional concerned groups to take action. Although their voices were not heard immediately, they were activated. During the first ten years, Transmileno S.A. has implemented and improved several scripts to provide for these concerned groups – for instance, they have introduced voice announcements of

the following stops inside the buses and electric elevators to guarantee access to the high platform buses of the feeder lines.

In "The Map of Transmilenio" (Valderrama, forthcoming a), I show how the discussion and elaboration of the map of Transmilenio (a central script) re-configures the delegation of agency between passengers and different experts inside Transmilenio S.A.'s network of designers. The growth of the system increases its complexity, and operation experts are not willing to trade performance for a simplified understanding on the part of the users, as communication experts recommend. Therefore, there are increasing expectations for users to become expert navigators of Transmilenio. What the implicated actors fail to grasp is that the design of the map of Transmilenio is actually a redesign of the city as a circulating representation, as a visualized entity (Lynch, 1960), and this might have consequences, even for its physical evolution.

3.5 The Design of LTS and the city

As stated at the beginning of this dissertation, both the Metro and Transmilenio must be studied with the cities they constitute. Or more precisely, the Metro and Copenhagen and Transmilenio and Bogotá are *gatherings* of the same things (Law, 2004). A study of the urban sociotechnical systems, then, should inform the study of the urban that the system enacts and affects. I avoid saying "the urban that contains the system" or "the urban that is supported by the system" because the systems I have been studying *constitute* the urban. However, accounting for them is not accounting for the whole of the urban either. Therefore, this section is devoted to a discussion of the extent to which dealing with Metro is dealing with Copenhagen and the extent to which dealing with Transmilenio is dealing with Bogotá.

The conception of the city as "spatial forms, as economic units and as cultural formations" (Farias, 2009: 9) or as an integrated, unified, mechanical being, evolving into a state of civilization (Graham and Marvin, 2002: 38) is an ideal constructed and pursued in urban planning, architecture, institutional design and state policy since the 19th century and well into the second half of the 20th century (Graham and Marvin, 2001: 62-89). The main role transportation networks play in this established image of the city is that of a service network that should be organized around territorial authorities that manage from an integrated monopolistic perspective. Perhaps the experiments of organizing transport and traffic in HT in the Greater Copenhagen Area or centralized in the Secretaría de Tránsito y Transporte in Bogotá were attempting to live up to this ideal.[5]

However, recent studies in the intersection between STS and urban studies propose a different understanding of the city, for example as an assemblage:

[5] HT stands for Hovedstadsområdets Trafikselskab, which was a state company responsible for coordinating the investment in and operation of all modes of transport in greater Copenhagen since 1974. In 2000, HT was disaggregated into various other companies. Secretaría de Tránsito y Transporte had the nominal responsibility for the design and coordination of transport and traffic in Bogotá since the 1980s. In 2007, it was merged with Transmilenio S.A. to constitute the Secretaría de Movilidad of the city.

> The notion of urban assemblages in the plural form offers a powerful foundation to grasp the city anew, as an object which is relentlessly being assembled at concrete sites of urban practice or, to put it differently, as a multiplicity of processes of becoming, affixing sociotechnical networks, hybrid collectives and alternative topologies. (Farias, 2009: 2).

Other authors have proposed to understand the city as a sociotechnical process in order to avoid the ontological separation of infrastructure from the urban (Graham and Marvin: 2001: 178-179). Therefore, studying a service network such as a transportation system is studying the city. The question then is, what are the sociotechnical dynamics of this multiple entity?

One possible answer is proposed by Graham and Marvin (2001). Their splintering urbanism thesis states that "a parallel set of processes is under way within which infrastructure networks are being 'unbundled' in ways that help sustain the fragmentation of the social and material fabric of the cities" (2001: 33). Unbundled infrastructures are those that are not developed as state monopolies with the ideal of universal access in mind. On the contrary, these are fragmented infrastructures developed as private businesses, not to deliver a universal service but a commodity. This process produces several specific spaces that can be rich in connections, and thus wealthy and protected, like premium network spaces, or strongly segregated and disconnected spaces. The principal difference between the two is the number of connections and opportunities that are highest for the former and lower for the latter. Thus, a new measure of richness and poverty can be understood in terms of the number of possible connections people have to everything and to everyone else. This thesis has been contested by scholars that argue that both positive and negative segregation have existed in cities, even when the ideal of monopolistic management and the integrated city was in full swing (Coutard, 2005).

Both Transmilenio in Bogotá and the Metro in Copenhagen were proposed as premium networked spaces (Coutard, 2005: 59) – spaces that provide premium service, but whose character is neither defined as privatized spaces, nor as targeting wealthy citizens. However, the designers did intend to develop a special space. In Bogotá, the designers pursued the creation of a standardized and disciplining space to break with the *other* pre-modern service provided by old gallery buses, a new space for a new citizen culture (Gómez, 2004; Valderrama, 2009). In Copenhagen, designers sought to provide a high-end, high-speed connection in central Copenhagen to integrate the medieval city and the new town of Ørestad. The old ideals of citizen culture and integration are still present in these two cases; nonetheless, the means to achieve them have changed. Both Transmilenio and Metro were carefully designed as separate sociotechnical systems to produce a new re-organisation in the arena of development of transport, but the intervention was not a deliberate intervention in the arena as a whole.

One particular script where this is evident is in the introduction of new stations in the city. In the case of Bogotá, Transmilenio introduces a radical change in the topology of the city. Whereas the principal organizing element of the city was the Cartesian grid, the construction and growth of Transmilenio has increasingly made the trunk lines and the stations the main structural element (Valderrama, forthcoming a). Where there used to be a continuum in real and perceived space, there now exists a fragmented space where

the “tunnelling effect” (Graham and Marvin, 2001: 201) has been introduced and saturated into the city. This has material effects on such aspects as property value, which can depend on whether property is close to or far from stations, or on the travel time between stations and between areas of the city.

The case of Bogotá is the case of a city where a new system was introduced to provide transport to areas already built and inhabited. The case of Copenhagen is different: the Metro introduces a particular topology of stations in the area of Amager, southeast of central Copenhagen in areas with a strong development potential. The location of the stations is intended to produce a rise in land values in order to make the whole vision of Ørestad and Metro economically possible. In this case, the designers considered the choice of technology, the layout of the new transit system, and the location of the stations, all as scripts that carefully had to contribute to make the whole new town possible. The new city and the new infrastructure were therefore one and the same “contested gathering of many conflicting demands” (Latour and Yaneva, 2008: 86).

The above analysis only makes sense if the city is understood as an in-here-ness instead of an out-there-ness, as something enacted permanently instead of something ontologically given; and as a gathering of multiple things, instead of a bounded integrated object (Farias, 2009: 13). Therefore, the notion of arenas of development fits the idea of the city as an assemblage highlighting dynamics of competition, complementarity and mutual shaping of the different elements, technologies and gatherings that make up the city.

The city and its technologies are co-shaped during the transformative process. One important aspect of the process is the configuration of visions for the city. In both Bogotá and Copenhagen, the designers developed a vision for the future of the city. Without that vision, the projects would not have been possible. But it is also the case that the vision itself was influenced by the way the transportation projects were developed. This vision is not outlined only by politicians, as Ardila-Gómez suggests (Ardila-Gómez, 2004: 419-420). As I show in this dissertation, it is co-constructed in political discussions, technical considerations, expert studies, and the materialities of the city itself.

The picture of design as a contingent process of intervention in an arena of development entails that there is no better rationality to appeal to, which also undermines the idea of holistic or monopolistic management of cities and cities’ services (Graham and Marvin, 2001: 42-49, 60). Therefore, planning and designing in urban settings should be understood in a new way:

> Imposing some simplistic notion of order or representation on such places is not only a power-laden act, but it is an arrogant act which privileges the ‘technical’ knowledge of the ‘expert’ over all other forms of knowledge, experience and opinion. And, suggests David Harvey, ‘since the metropolis is impossible to command except in bits and pieces, urban *design* (and note that postmodernists design rather than plan) simply aims to be sensitive to vernacular traditions, local histories, particular wants, needs, and fancies’ (original emphasis). (Graham and Marvin, 2001: 112).

By replacing "building" with "transport system" in Latour and Yaneva's (2008: 87) eloquent analysis of the transformations of a building, the role of transport systems in cities emerges as a richer set of constitutive moving and fluid elements:

> We should finally be able to picture a [transportation system] as a *navigation* through a controversial datascape: as an animated series of projects, successful and failing, as a changing and criss-crossing trajectory of unstable definitions and expertise, or recalcitrant materials and [design] technologies, of flip-flopping users' concerns and communities' appraisals. That is, we should finally be able to picture a [transportation system] as a moving modulator regulating different intensities of engagement, redirecting users' attention, missing and putting people together, *concentrating* flows of actors and *distributing* them so as to *compose* a productive force in time-space.

4. Methodology

4.1 Case study research

The eclectic character of this dissertation is not limited to theories and concepts, but extends to the methodological approach. As indicated in chapter one, the main motivation to study design processes came out of an interest in doing engineering: in contributing to the understanding of how to create a new system. Engineering education is based mainly on normative approximations to such processes like those represented in figure 12.

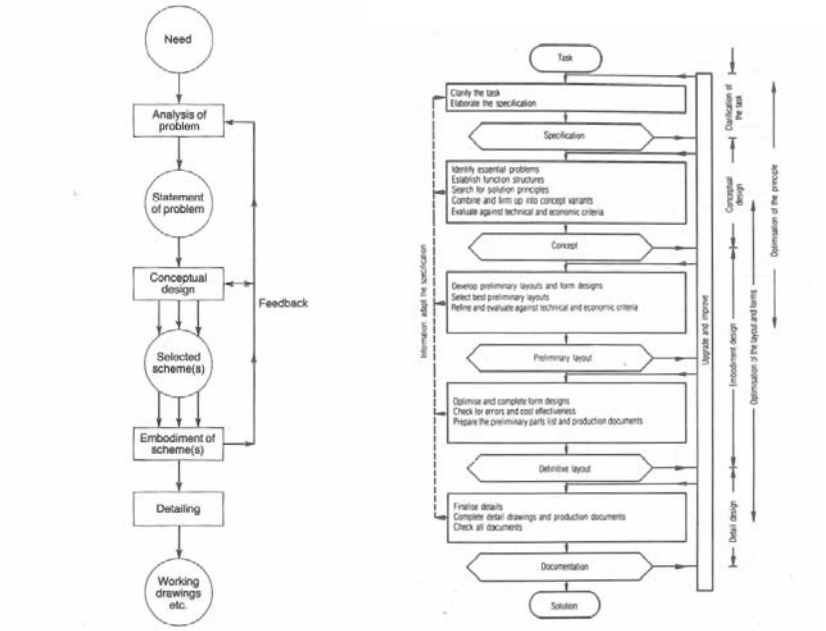

Figure 12: Diagrams showing schematically how engineering design processes should be (Dym, 1994: 25, 31).

Some experienced engineers have moved away from these schematic ways of understanding design and planning processes (Leleur, 2005). However, their view of design or planning processes still pictures politics as external to the technical project, like a gray cloud (figure 13), thus conveying the idea that while the technical is susceptible to systematization, the political is not.

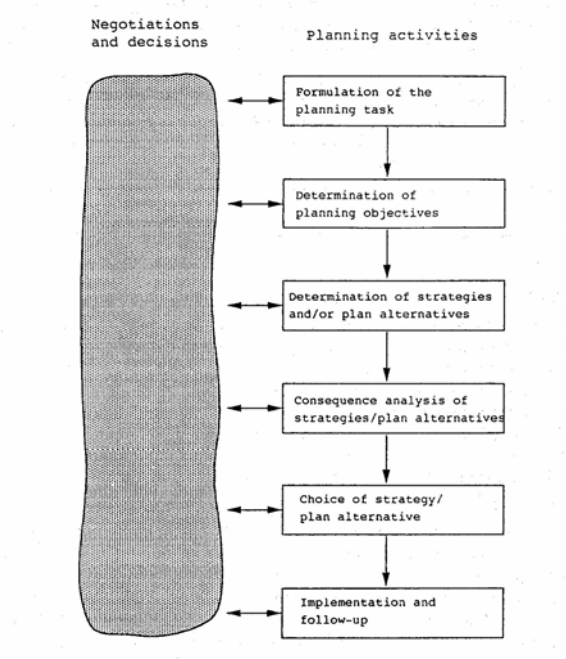

Figure 13. Diagram showing the relation between planning activities (rational and ordered) to the right, and negotiations and decisions (messy politics), the gray cloud to the left. Image taken from a slide of a presentation of Professor Steen Leleur, Course of Planning Theory, September 4, 2007.

With the above in mind, my justification for using case studies is connected with the fact that I wanted to examine in detail some design processes in order, first, to discover if normative approaches were valid (like many of the other cases I refer to in this analysis: for example Ardila-Gómez, 2004: 13; see also Johnson, 2009). Second and most importantly, I wanted to produce a rich description (Bender, 2009; Flyvbjerg, 2006; Yin, 2003) of some cases that would allow for further theorization and discussion.

One important case study that has served as a methodological inspiration to my work is Bruno Latour's study of the design of the personal rapid transport system ARAMIS in France. Looking back on the study itself, Latour acknowledges that this particular case study had a very important impact on his whole carrier, since it provided a basis for discussing how difficult it is to present a project as opposed to objects that seem so definite, especially in engineering (Blok and Jensen, 2009: 225). What Latour did in that study was to "follow the actors" (Latour, 1996: 18), which today has become the oversimplified slogan of ANT methodology. However, the process of following the actors has many elements. In the following, I make these elements explicit so the reader can understand the scope and limitations of my own analysis.

Like the study of Aramis, and Hughes' study of CA/T, my study is based on document compilation, analysis and interviews conducted with designers, planners, technicians and other persons that participated in the design of the systems, or have studied the process, or that were excluded from the process. Like the study of Aramis or CA/T, my study has struggled not to impose theoretical categories on the materials collected, especially on what the interviewees elaborated. On the contrary, I have done my best to respect the interviewees' own accounts. This special feature is what makes ANT

practitioners, and especially Latour himself, talk about ANT as a methodology rather than a theory.

I have used several case studies – those that have been presented under the labels ANT, LTS, and arenas of development – as inspiration to elaborate my own cases. I have followed the material scripts, as a way of following the actors in order to investigate the role of visions, politics and knowledge in the development of large technological systems.

In ANT ethnographies of laboratory practices (for example, Latour and Woolgar, 1986), and in reconstructions of practice based in interviews (Latour, 1996), the authors have concentrated on the way practitioners make sense of their own activity. I have adopted the same strategy here, but instead of focusing on laboratory practices, I have focused on the genesis, stabilization and agency of particular material scripts. In this respect, I have adopted a *method assemblage perspective*, which proposes to abandon the idea that an object, a system, an idea, or knowledge itself, exists out-there, is independent, is anterior, is definite and is singular. (Law, 2004: 21). Instead, the qualities of terminated objects and systems *are made to happen* through design, through a network of support and constitution, through the undoing of existing connections, through the establishment of new connections, through visions. In my research, I have accounted for the process by which designers struggle to produce a system that exists out-there, is independent, and can be told in a narrative that makes it anterior, is definite and seems singular. By tracing the genesis and nature of material scripts, I have reached out to the ways in which designers define visions, struggle to align actors and assign meaning to the elements that make the systems exist.

Like Latour in Aramis and Hughes in CA/T, I have had access to the process of design through interviews and document analysis and through an approximation to the communities that constitute the systems. Following the scripts, as I have done here, can also be understood as a way of following the actors as scripts become actors that enact the system (and the city). By looking at the scripts, I have thus attempted to re-construct the ways in which designers created presences (the final chosen scripts), which are co-dependent on those that are manifest but not present (alternative scripts), in a process of translation where traces have been covered – or to put it another way – where many other things that make possible and actual scripts have been *othered* (Law, 2004: 83-85). In all these processes, designers are not the starting nor the ending point, but actors that attempt to re-order the world. In this sense, designers do things, but they are also influenced by visions, politics and the dynamics of the arena of development in which they operate.

To uncover this process, interviews are also important, because they reveal what was left behind, what was considered but discarded, that which Law calls *manifest absences*, like the closed overground Metro stations in Copenhagen or low platform buses in Bogotá. In some cases, I have been able to retrieve those elements that were *othered* – that is, those elements that were covered, like the dismissal of concerned groups during the design of the first phase of Transmilenio. This process however is the most complicated to uncover, because interviewees, especially those that still have a strong relation to the systems they helped to create, are interested in covering traces, in

presenting the outcomes of design as *facts*, in making them the best choices, through the narrative of the interview.

The limits of my method assemblage are connected with the project's dependence on interviewees' own accounts. The selection of scripts has been guided by what my interviewees refer to, rather than by a rational selection of the main features to be analysed. The interviewees have also elaborated on their readings of the history of the arena of development to talk about the scripts. Therefore, the references to the arena of development is not a layer of explanations I add to the analysis, but something that emerges from the sources of the research.

To sum up, my methodology is based on the principles of ANT – agnosticism, symmetry, and free association. These have been the guiding principles of my research, and they are central to LTS, ANT and arenas of development theory. As many proponents and practitioners of these theories argue, they are not so much theories but rather methodologies (Law and Hassard, 1999), because often the boundary between theory and methodology is not a clear and definite border. In addition, these methodologies do not suppose *a priori* that the world out-there has any kind of pre-defined structure or geography. Rather, they argue that the form of what becomes out-there emerges from the dynamics of multiple gatherings (Law, 2004). I have reached out to the process of *gathering* in Transmilenio and the Metro through my interviews and the documents I have consulted.

4.2 Data collection methodology

Materially my study is based on three elements. First, there was a visual examination of the systems in order to determine their main components or features on location –what I have called material scripts, that is, those that came to be integrated into the system and made it work. These are the scripts that became actors of the working system. Among them are the automatic trains, the open overground stations, the high platforms, the stations in the median, the dedicated lanes, the wheel chair elevators and so on.

Second, in each case, I have examined a number of different types of documents. On the web pages of the Metro www.m.dk and Transmilenio www.transmilenio.gov.co all traces of the process of developing the systems have been almost completely deleted. But other working documents like academic papers, public hearings, internet blogs, and technical studies are good sources that inform the analyst about the alternative scripts considered for many technical decisions, those scripts that became manifestly absent – trams instead of trains and closed overground stations instead of open ones in Copenhagen; CNG engines, low platforms or route-based maps in Bogotá.

Third, I have conducted a number of interviews to ask the planners, designers, technicians, politicians about the process of definition of the main features of their systems: the design process. For the most part, the interviews were non-structured and open. Loyal to the principles of ANT and method assemblage, I built my analysis on some of the issues and scripts my interviewees talked about. I did not analyse everything, because of the constraints of time and resources, and because I decided to concentrate on a few scripts in order to achieve what grounded theory proponents call

saturation (Glaser and Strauss, 1967). Saturation is when the researcher reaches the point where new interviews do not add new information.

I visited the documentation centres of Transmilenio S.A. in Bogotá and of various institutions in Copenhagen, including Metroselskabet A/S, the Royal Art Academy's Architecture Library, and the documentation centre of the Department of Transport at the Technical University of Denmark, where I identified several key documents. I include the documents used in the reference list in section 6.1. The names of the interviewees, with the place and date of the interview, are specified in section 6.2.

5. Conclusions

5.1 Main findings

To the question of how do designers conceive and define the main features of urban transportation systems, I propose the following answer:

> Designers discuss and define *scripts* that make up the transport system and the city. During the process of definition, designers make readings of the history of the *arena of development* for transport and *distribute agency* to the defined elements in order to make it work and make it stable in time. The defined elements are thus a precarious stabilization that relates to the humans and non-humans that compose the *system*. During the process, the actors involved change, including the designer group. Current and future users also play a role in the process in the form of real or represented users or concerned groups. Because of the scale and character of the transport systems considered here, the process of definition of specific *scripts* entails a dynamic of undoing established connections and proposing new ones in the *arena of development*. The nature and extent of the connections are such that the whole process involves transformation of the city.

In the process of this work, I have analysed scripts in various phases of the project's becoming: the choice of technology in Copenhagen's Metro, for example, belongs to a discussion that took place in the conceptual design phase of the system. Likewise, many scripts of Transmilenio and Metro, like high platforms, dedicated lanes, open overground stations and object detection systems, were defined during the detail design phase. Others, like the elevators for handicapped users or the map of Transmilenio, were developed during the operation and growth of the system. What they share is the fact that they all became material scripts: they were produced in specific shapes, materials and locations. Once stabilized, they became actors in the emerging configuration of the system: this means that the scripts supported or sabotaged the operation of the system locally or globally, and/or the future growth of the system at different moments in time. This relative un-stability and un-controllability of the scripts in relation to what they do for the rest of the system happens because designers delegate agency to the scripts in ways that reflect the negotiations among the diversity of designers. This shows how the process of delegation of agency is contingent. It also allows seeing that this contingency is due to the fact that the designer group is an entity composed of many people, different forms of knowledge and non-human actors, whose size and identity varies in time and with the process of script definition and delegation of agency. All these processes happen in an evolving arena of development already populated by other systems, rules, knowledge, actors and histories. When designers discuss and propose something new, they necessarily mess up the whole of the arena of development, producing both expected and unexpected developments.

Another important feature in the design process revealed through my research is that the designers engage in processes of knowledge accumulation and script definition from a

protected space for action, which I have characterized as an extended laboratory. In the two cases, these spaces were, first, appointed working groups heavily supported by the cities' administrations, and later on, they became whole new institutions that departed from the established knowledge regarding the design and operation of public transportation systems: they became system builders in Hughes' sense (Hughes, 1983; 1998). Right from the beginning, this core designer group had a technical and political capacity to start working. Through processes of contracting, surveying, inviting others, enrolling experts, making public hearings, tendering etc., these designers engaged in various parallel processes: they accumulated knowledge and they enrolled supporters for the project. These processes also entailed changes in the quantity and character of the members of the design group, which is also related to further accumulation of power and their respective trade-offs.

The designers thus did not act in a void from the beginning; they acted in an arena of development where other actor networks and systems already existed and configured what the city was. When designers started developing a new system, they engaged in processes of analysing the history of the arena. These entailed making readings of the past and present conditions and projecting desired developments into the future: attaching the future of the project to visions of what the city should be. Designing a new transportation system was, thus, a process of intervening in the arena of development. It was a process of attempting to undo established connections and trying to configure new ones. Designers performed the intervention in the arena of development at various locations, including city administration offices, public hearings, parliamentary discussions, technical reports, tendering processes etc; there was no special meeting where the essence of the project was decided. Instead, a slow and multi-sited process of crafting the multiplicities that constituted the system and its context took place. The arena of development for transport extended geographically into the world at large, as current and possible transport technologies were supported and criticized by global networks of experts, academics, other working systems, economies, and cultures. As I have argued, this process of intervening in the arena of development *is* a process of intervening in the city.

The fact that I have focused my analysis on the core group of designers does not mean that this group acts alone; this group was heavily supported politically and endowed with resources to start working. In this sense, it resembled the idea of a "capable agency" (Ardila-Gómez, 2004: 23). However, I have emphasized that through the processes of design they also enrolled others who also became designers, such as consultant firms or the private operators in the Transmilenio case. Designers enrolled a number of consultant firms that actually did conventional engineering measurement and design, such as origin-destiny matrixes, shaft design, automation design and so on. The core design team also rejected others that either became tolerant users, non-users or implicated users. Therefore, one important role of the core design team is deciding who will become part of the valid knowledge-accumulating process and who will be assigned a passive role.

In the long run, however, the distribution of agency to different scripts could and did cause designers and operators themselves trouble. This is illustrated in the case of Mr. Bermúdez (Valderrama, forthcoming), who successfully sued Transmilenio S.A. for not

providing accessibility for persons in wheelchairs on the feeder routes. The positive result for Mr. Bermúdez is owed not only to the lawyers and magistrates that defended his position, but also to the many material scripts that made accessibility possible in the trunk lines. The fact that these existed made it difficult for Transmilenio S.A. to maintain that it was prepared to deliver accessibility in only one part of the system (the trunk lines) and not in another (the feeder routes).

The performative character of material scripts is also illustrated by the object detection system of the Copenhagen Metro. Although the device worked perfectly well to make the system safe, it also posed problems for the operation of the system itself. Although designers may regret the decision to install the system, it is part of the design of the open overground stations as a whole, and the cost of changing the script is high once it is materialized. The lower costs and the work carried out in the current configuration makes the design obdurate; not even the same designers that made them can change their minds. The creators are now disciplined by their creation.

5.2 Reflections

I have approached the Metro and Transmilenio as designed sociotechnical systems, with the aim of producing a conceptual understanding about the process of design that can also be applied to systems that are *not* innovations. The concept of arenas of development has been relevant, because it places the new system in relation to the others that exist, and whose existence is also produced. Therefore, the idea of undoing connections and making new ones fits with the conceptualization of innovation, not as a process of *introducing* but of reconfiguring or reordering. What, then, is the conceptual basis to explain that Metro and Transmilenio are innovations? I do not think that my study answers this question, but I do believe that there are some valuable elements. The first one is that both Metro and Transmilenio were, from the outset, embedded in ambitious projects of city transformation; they were part of powerful visions for the city. However, these projects were not only paper plans. They were supported from the outset by a network of powerful politicians at the city and country level. This explains that the initial team or committee counted on the necessary resources and support. The composition of the initial design team was also a key element; in both cases, capable technicians with experience in public administration and politics were part of the core design groups. What my analysis further adds to this picture is that the process of knowledge accumulation, of enrolling other actors, of further protecting the design space, of accumulating power, not only involved interacting with other human groups and institutions (Ardila-Gómez, 2004; Hughes, 1998), but also intervening in the arena of development and delegating agency to material scripts.

What then is the type of expertise needed to become part of the designer actor of such systems? The composition of the initial teams in Bogotá and Copenhagen has two elements in common. First, they were staffed by experienced technicians in city administration and politics. The initial members knew how their cities were governed and what was the fate of technical practice in public institutions, and did not only represent the private sector. Second, they were interactional experts (Collins, 2010) who accumulated even more interactional expertise as they developed the projects. An interactional expert is a person that has the capability of mobilizing contributory

experts. Persons with contributory expertise have been trained and have practiced a specific form of knowledge in order to authoritatively produce a concept, a recommendation or an inscription. For example, transport3 engineers produce origin-destiny matrixes that model the behaviour or passengers in cities; experts from management consulting firms produce recommendations for institutional design; lawyers produce knowledge of legal conditions for action, and of strategies to legally support developments and so on. Collins states that interactional expertise is the capacity of one expert to understand the technical language of another expert, without ever being trained in that other expertise or having practiced it (Collins, 2010). The cases of Transmilenio and Metro show that the designers were able interactional experts and further accumulated more power to interact and intervene successfully in the arena of development of transport.

Was it a democratic process? My cases show that the development of infrastructures for mobility in urban environments, like Transmilenio and Metro, required measures that might seem undemocratic. For example, these two projects share the fact that they were provided with extended laboratories that were carefully protected from public intervention. Many technical decisions and definition of scripts were made without public participation. Although there were instances of participation, such as public hearings, the majority of the scripts of both systems were defined by the core design group, against the opinion of affected groups (for instance the inhabitants of the populated areas of Amager in the case of Metro), but attentive to technical criteria and sociotechnical dynamics. However, both projects were pursued and supported by democratically elected city administrations. Therefore, the issue of democracy is more nuanced in these cases.

In extension of the above, it is also interesting to note that at least in the case of Transmilenio the new system provided opportunities for passenger action. In fact, the configuration of Transmilenio as a system coordinated by one agency that is responsible for the service, the stations and the dedicated lanes, has produced a configuration that makes it possible for passengers to block the system and demand attention. On several occasions, passengers have stepped down from the stations into the lanes to sit down and protest against the quality of service or the deficient number of buses. Mr. Bermúdez succeeded in mobilizing Transmilenio S.A. to improve accessibility in the feeder lines for the handicapped, for example with elevators in the buses, because in the new institutions the delegation of responsibilities was clear and the higher courts could actually rule in favour of Mr. Bermúdez by ordering Transmilenio S.A. to provide for accessibility. That possibility did not exist before Transmilenio. In the *transporte público colectivo,* the institutional arrangement, the over-regulated normativity and the configuration of vested interests is such that neither the Secretaría de Tránsito y Transporte, nor the bus company owners, nor the bus owners and drivers, were *mobilizable* even by the higher courts of the countries to consider handicapped people in the provision of public transport.

5.3 Future lines of research

The scope of this research as always has been also defined by a time frame, an institutional rhythm that demands a deliverable, and the community's call for results. However, there is more work to be done and in this section I outline four concerns which I would like to research in the near future: the possibility of developing normative models for design; the sociotechnical dynamics of the further growth of Transmilenio and Metro; the role of designers and users in the fate of these systems; and the ways in which knowledge in transportation theory change due to these interventions.

Science and Technology Studies and History of Technology scholars have traditionally been timid to take up the task of producing normative models. For example Hughes's phase model for the evolution of large technical systems (Hughes, 1983; or ANT scholar's references to a whirlwind model of innovation (Akrich, Callon, Latour, 2002; Latour, 1996), have not become schematic working models taught at universities and used for policy making. These fields tend to privilege rich descriptions, case studies and the development of new perspectives based on empirical research. However, after several decades of case studies, many scholars in these fields are taking up the question of the possibility of producing some normative knowledge with regards to the sociotechnical processes of knowledge production and technology development. The increasing focus in practices like design, architecture, urbanism and engineering from the rich perspectives of these fields might be reaching a propitious moment to consider this possibility. I think that the analysis of the design of Transmilenio and Metro can contribute to this discussion.

At the moment of writing these lines, both Copenhagen's Metro and Bogotá's Transmilenio are growing. In fact the circle line is being developed in the capital of Denmark and phase three of Transmilenio is also in the construction phase in Bogotá. These developments hit the headlines of the newspapers of their countries often. They entail the consolidation of some scripts, the modification of others, and the development of new ones altogether. In turn, these processes will re-distribute causes and agency in the arena of development of transport in both cities. Therefore, a new Copenhagen and a new Bogotá are unfolding at this very moment. However, these systems are not new players in the arenas of development of their respective cities; they are established players that grow. If the conceptual framework proposed in this dissertation is robust enough, it should also be useful to account for growth, not only innovation. I have advanced in that direction studying the constitution of the map of Transmilenio (Valderrama, forthcoming a). However, more aspects of both systems need to be brought into the analysis to test the strength of the framework and further adjust it.

In Bogotá, Transmilenio S.A. is now part of the Secretaría de Movilidad, which means that is no longer a new institution, but an established institution. It is staffed by many professionals; most of them hired after Transmilenio was already operating. The majority of the initial designers are long gone. In Copenhagen, the Ørestad Consortium doesn't exist anymore. In its place Metroselskabet I/S is in charge of operating the existing Metro and developing the new city ring, with Anne Grethe Foss as its vice-director. So in both cities there are established organisations that continue to steer the fate of the growth of the system. Are they comparable to the ones that produced change?

Have they become rigid? Could these institutions engage in innovative projects, or has their character become more obdurate? Further data and analysis are needed to research these questions, in order to produce knowledge on the dynamics of script definition, delegation of agency and re-configuration of the arenas of development in the phases of growth of these systems.

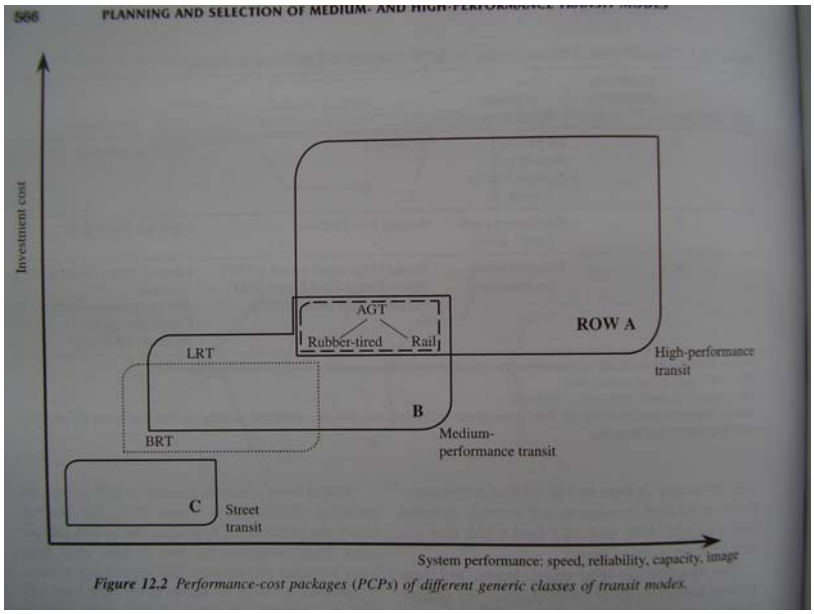

Figure 14: Diagram of performance-capacity against investment costs of various transportation modes as it appears in Professor Vukan Vuchic's book Urban Transit Systems and Technology (2007).

Users and actors are also changing. In both Copenhagen and Bogotá there are an increasing number of passengers for whom the days when Transmilenio and Metro didn't exist are becoming blurred memories. For them, these systems are the city and their material existence is not contested anymore. Furthermore, when campaigning for positions in the city council, in the city administration and even for the legislative bodies at the national level, politicians often have to take a position in front of these systems: will they support further developments? Would they *problematize* their performance? Would they propose the development of other systems? Just as the identities of the elements that constitute Metro and Transmilenio have changed, so the systems themselves. How to account for that process? And most importantly, how does the future development of the arenas of development of transport in these cities is determined by the existence of these powerful actors, namely the systems themselves?

Another element that is worth researching relates to the ways in which the existence of these systems and their further growth constitute a new development in the knowledge of various fields: urbanism, transportation, traffic engineering, etc. Just to outline an example: in 2007 two documents were published both making knowledge claims about the performance of different technological systems. One was published by renowned and authorised transport planner Vukan Vuchic from the University of Pennsylvania

whose books are widely used in education and research all around the world.[6] The other document was produced by Walter Hook from the Institute for Transportation and Development Policy and Lloyd Wright from University College in London, two strong promoters of BRTs in the world. Vuchic is an established authority in the field of transportation planning, engineering and technology, while Hook, Wright and all their collaborators have built their authority in the practice of developing urban bus systems in many places.

What the diagrams show is two very diverging views of the relation between investment in urban transit technologies and performance. As shown in Figure 14, for Vuchic BRTs are a new technology whose performances are not proven (hence the doted line in his diagram), and whose performances and investments lie in the region of light railway systems, but that by no means can compete with underground heavy rail systems (Vuchic, 2007: 566). As shown in figure 15, for Wright and Hook BRTs definitely compete in capacity with heavy rail systems while requiring considerable less investment costs (Wright and Hook, 2007: 72). The differences in the diagrams reveal that there exists a divergence regarding what is valid knowledge about investment vs. performance for BRTs. The established community of transport planners claims that is an inferior alternative to heavy rail, while BRT promoters claim the contrary. As new systems are built and the usual generational changes occur among academics, the diagrams are going to change. It is worth investigating both how they change and why, and what effects does this have in future projects.

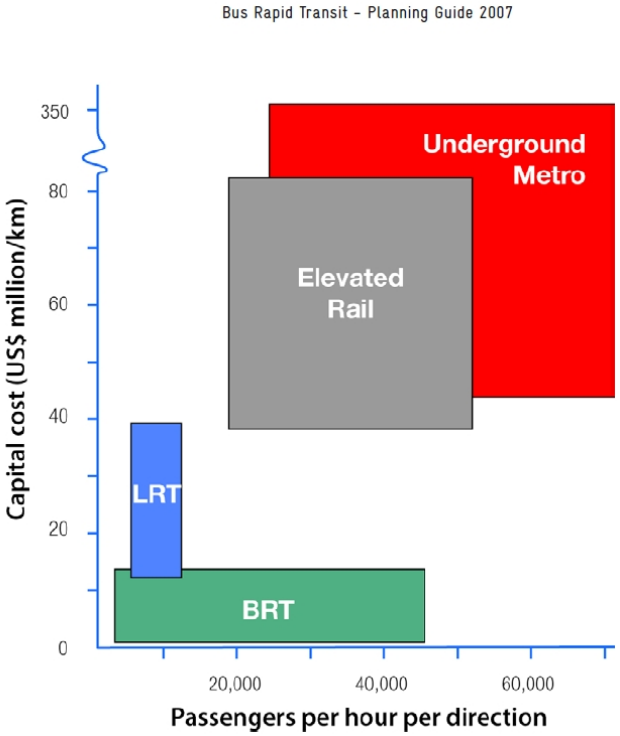

Figure 15: Diagram of capacity against capita costs as it is presented in the Bus Rapid Transit – Planning Guide (2007)

[6] I took the picture of Figure 14 in Colombia after borrowing the book from my colleagues at the Civil Engineering Department of Universidad de los Andes where they use this text to teach at undergraduate and graduate level.

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6.2 Interviews

Copenhagen
Helge Bay, 30 July 2007
Thomas Eirsted and Peter Jensen, Metroselskabet, 24 November 2008*
Bo Ekman and Henrik Backteman Larsen, Vejdirektorakt, 27 February 2008
Anne Grethe Foss, Metro A/S, 4 December 2008
Morten Petersen, Tetraplan, 24 July 2007
Jens Rørbech, DTU Transport, 30 October 2008

Bogotá
Howard Acuña, Bogotá, 23 August 2004
Mauricio Arciniegas, Si99, Bogotá, 9 November 2005
Juan Baquero, Si99, Bogotá, 9 February 2006
Phil Berczuk, Steer David and Gleeve, London, 4 March 2009 and 21 October 2009
Justo Bermúdez, STT, Bogotá, 8 November 2005*
Ignacio de Guzmán, Akiris, Bogotá, 10 March 2009
José Fernando Díaz, Bogotá, 8 November 2005*
Humberto Eslava, Ascopar, Bogotá, 27 Agosto 2009
Mauricio Gaitán, Bogotá, 27 August 2009
Luis E. Garzón, Mayor of Bogotá, Bogotá, 9 November 2005*
Walter Hook, Director ITDP, Bogotá, 9 November 2009*
German Lleras, Steer Davies and Gleeve, Bogotá, 10 February 2009
Dario Hidalgo, Bogotá, 9 November 2005 and 3 January 2007
Jaime Loboguerrero, Universidad de los Andes, Bogotá, 16 September 2005
Astrid Martinez, Transmilenio, Bogotá, 8 November 2005*
Milena Martínez and Fidel Martínez, Sotrandes, Bogotá, 4 July 2005
Víctor Raul Martínez, Si99, Bogotá, 3 September 2005
Juan Ricardo Noero, Vice-minister of Transport, Bogotá, 8 November 2005*
Andrés Pacheco, World Bank, Bogotá, 8 November 2005*
Enrique Peñalosa, Bogotá, 15 October 2005*
Gregorio Perez, Bogotá, 9 November 2005
Mariano Pinilla, Bogotá, 20 February 2009
Alfonso Prada, City Council, Bogotá, 18 November 2005
Garrone Reck, Bogotá, 11 November 2005
Margarita Rivera, Sidauto, Bogotá, 6 September 2006
Néstor Rojas, Universidad de los Andes, Bogotá, 8 April 2006
Orlando Santiago, Transmilenio, Bogotá, 2 March 2009
Juan Carlos Díaz, Akiris, Bogotá, 2 September 2005
Ricardo Wagner, Bogotá, 5 April 2005

* These interviews were somewhat different, because they consisted of a public presentation followed by some questions on my side.

Article appendix

Diesel vs. CNG (2007)

Valderrama, A. & Beltran, I. 2007. **Diesel versus compressed natural gas in Transmilenio-Bogotá: innovation, precaution, and distribution of risk**. Sustainability: Science, Practice, & Policy 3(1):59-67. http://ejournal.nbii.org/archives/vol3iss1/0608-025.valderrama.html.

During the period 1998–2000, municipal officials in Bogotá implemented a new transportation system for the city. Transmilenio became the first major mass transportation system in the world to use only buses. The authors examine here the process that led to the design decision to power all of the buses with diesel fuel. The main finding is that the various public and private partners sought to accommodate themselves to the alternative that was deemed to be less risky. The diesel option was the outcome of contingent negotiation and distribution of responsibilities among the different interests. The dynamics of these processes were heavily influenced by a precautionary posture.

Diesel vs. CNG in Transmilenio-Bogotá:
Innovation, Precaution, and the Distribution of Risk

Andrés Valderrama and Isaac Beltrán

Thanks to my co-author Isaac Beltrán and to the editors of SSPP Maurie Cohen and Amy Forrester for permission to re-print this preliminary version of the paper.

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Sustainability: Science, Practice, & Policy 3(1):59-67.
http://ejournal.nbii.org/archives/vol3iss1/0608-025.valderrama.html.

Introduction

On December 1, 2000, a new fleet of 450 articulated buses began to provide transportation services along the main urban transit corridors in the city of Bogotá, Colombia. The fleet replaced approximately 1140 older buses and served about 850,000 passengers per day. From a technological perspective the new fleet was entirely different from previous bus fleets, but in one significant way the new fleet was continuous with the existing bus system: it was powered by diesel fuel.

The construction of the new bus system involved many organizational and technological choices, but one of the most controversial was the decision to use diesel fuel rather than compressed natural gas (CNG). From a broad sustainability perspective, both diesel and CNG are fossil fuels that generate greenhouse gases, and both are resources that appear to be at or near peak production at a global level. However, several factors might have favored the choice of CNG. The country of Colombia had extensive natural gas reserves and was encouraging conversion to natural gas vehicles, and the city of Bogotá had earned an international reputation for sound urban planning and concern with issues of sustainability and innovation (e.g., Institute for Transportation and Development Policy 2006). Moreover, at the time that decisions were being made, CNG was a much cleaner fuel that promised significant environmental and health benefits for the Bogotá region, whereas continued use of diesel as the public transportation system's main fuel presented unknown long-term risks of increased incidence of cancer, asthma, and other diseases (El Tiempo, 2006). Indeed, as Alfonso Prado, a member of the city council, noted, "In the city council the debate was around what was the cleanest fuel. That is what really matters; it was the essence. Which one pollutes less? There is no debate about costs" (Interviewee #8).

Prado's comment suggests that the precautionary principle, rather than a narrow cost-benefit calculus of the trade-off between health risks of continued diesel emissions versus the operational costs of conversion to CNG, guided the thinking of at least some members of the city government about the issue of emissions, air quality, and fuel preferences. Had the precautionary principle been translated into system design choices, the model bus system of Bogotá might have been fueled by CNG. However, something

happened on the way from principle to practice. This paper will provide a post-mortem analysis of the CNG-diesel controversy in Bogotá. Although the history is interesting in itself because it provides a comparative perspective on the CNG-diesel controversy that has been raging in other countries (Hess 2006), the case study is also used here to provide an opportunity to open a broader discussion of some of the problems that can emerge in public-private partnerships where the public risk of health and environmental concerns collides with the private risk of businesses that are concerned with the potential for technological failure and loss of profitability. Although we note, like Ferguson (1997), that there are some limits to privatization, we attempt to delineate some strategies for successful public-private partnerships where two different notions of risk need to be negotiated and the technological choices are not straightforward.

Background

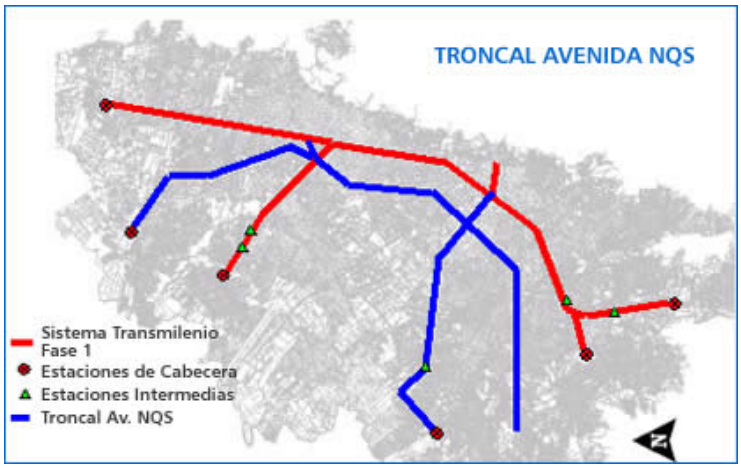

Figure 1: Phases 1 (red) and 2 (blue) of the Transmilenio project in Bogotá, Colombia. Picture retrieved from the Instituto Distrital de Urbanismo http://www.idu.gov.co/sist_trans/troncales.htm the 27th of April of 2006.

The term "Transmilenio" designates three different entities: the government agency Transmilenio, S.A., which manages the system; the project "Transmilenio," which is a long-term public works effort that includes both public and private sector partners; and the infrastructure and functioning of the transportation system. As an organization, "Transmilenio" refers to the public agency that coordinates construction and maintenance of the infrastructure and manages contracts with the bus operators and money collectors, both of which are private-sector firms. However, the term "Transmilenio" also refers to the ongoing project of the agency. Originally developed between April 1998 and December 2000, the project drew on the expertise of engineers, economists, managers, and attorneys to design and implement an entirely new technological system for the main corridors of Bogotá. The plan involved various phases, of which only the first (Avenida Caracas, Avenida 80, and Autopista Norte) is fully completed. The second phase (Avenida Suba, Avenida Norte Quito Sur, and Avenida Américas) was still under construction as of 2006, and subsequent phases were planned with the goal of eventually having a system in which no point in the city was farther than 500 meters from a transit stop. (See Figures 1 and 2.)

Figure 2: Routes (left) and coverage (right) within a 500m range from routes when all phases are built and into operation. Sandoval, Edgar. "La Nueva Industria del Transporte para Bogotá", public presentation in the Primer Seminario Internacional de Transporte Urbano TransMilenio: La Experiencia de Bogotá. Bogotá, November 14th, 2001. Edgar Sandoval was then the CEO of Transmilenio S.A.

As infrastructure and technology, the term "Transmilenio" refers to the bus rapid transit design that separates public bus traffic from private automobiles and taxis and that provides passenger access via stations located in the middle of the road. (See Figures 3 and 4.) The body of the new, articulated buses is completely redesigned by professional designers as well as engineers, the motors on the new buses use the most recent technology, and the gearbox uses the latest developments to ensure a smooth acceleration for the comfort and safety of the passengers. The new buses have a capacity of 160 passengers and an average speed of 28 km/hour, in contrast with the previous capacity of 80 passengers and 15 km/hour.

Figure 3: Picture of the system to illustrate how the bus traffic is separated from the private car, the public taxi, and the service traffic. Stations are in the middle of the road and the access is provide by pedestrian bridges. Picture retrieved from Transmilenio S. A. web page http://www.transmilenio.gov.co/transmilenio/frameset_gneral.htm the 27th of April of 2006.

Transmilenio was established as a solution to the problems of the existing bus system in the city: the "transporte colectivo". When Transmilenio was inaugurated in 2000, the 850,000 passengers that it soon carried represented only about 12% of the total daily trips on public transit in the city, and as of 2006 the existing bus system (*transporte colectivo*) was still responsible for about 60% of the bus trips in the Bogotá (private cars amount to 15%, Transmilenio to 23% and other modes –cycling and walking- to 2%

approximately). The existing, *transporte colectivo*, bus system was based on a system of competition among private carriers that resulted in an excess of vehicles on the streets--approximately 22,000 vehicles when the city only needed 8,000 according to transportation experts. The excess vehicles created unnecessary air pollution, traffic congestion, and a high number traffic-related accidents and fatalities. (See Figure 5). The system operated as follows: passengers paid drivers directly for the trip, the driver paid the bus owner a proportion of the revenue collected, and the owner paid the company a fee for the route. The system resulted in complete but overlapping coverage of the city, high frequency, intense competition for passengers, and passenger pick-ups at any point on the street rather than at designated bus stops. Although the system worked, it also generated significant corruption among the regulatory bodies that were in theory responsible for establishing and enforcing the rules for the sixty-four bus companies in the city. With the advent of Transmilenio, the system design changed so that passengers paid in the station when they entered the system, not on the bus. Drivers were given a formal contract with the company, and they were also provided with schedules, uniforms, training, break time, a lunch hour, and other benefits (see Ardila 2004).

Figure 4: conceptual representation of the Transmilenio System. Picture retrieved from Transmilenio S. A. web page http://www.transmilenio.gov.co/transmilenio/frameset_gneral_us.htm the 27th of April of 2006.

The analysis that follows is based on two sources: documents available from the various public agencies associated with the Transmilenio project, and interviews with ten leaders who participated in the planning and development of the project. The authors also draw on their personal experience with the Transmilenio bus system and professional experience with engineering in Colombia. In the tradition of technology studies, we assume that system design decisions are driven by a mixture of technical and social factors, and that technical design factors can become aligned with broader political and social divisions (e.g., Bijker and Law 1992).

Figure 5: Pictures taken by the authors in the streets of Bogotá. They reveal how buses, taxis, and private cars work in a mixed traffic situation, the superposition of routes, and the competition for passengers.

CNG, Petroleum, and National Energy Policy

On the surface the high level of organizational and technological innovation of Transmilenio might have lent itself to innovation in fuel sources. Furthermore, the fourth largest city in the country, Barranquila, had already successfully run 4000 buses powered by CNG, so there was already significant experience with CNG technology for public transit in the country (Ministry of Transportation 2006). The city of Bogotá also had a few stations that provided CNG, and many vehicles, mainly taxis, had already been converted to operate on CNG. By the late 1990s there was also considerable experience in fleet conversion to CNG in other countries, such as the United States (Hess 2006).

Furthermore, to some degree changes in Colombia's national energy policy had facilitated the conversion to CNG. In 1999 the country deregulated gasoline prices, a change that resulted in rapid price increases in gasoline. Both diesel and CNG remained regulated and therefore relatively low with respect to gasoline. Consequently, owners of public transportation vehicles, who up to that point had primarily used gasoline, began converting their vans and buses to either diesel or CNG. Because Barranquila is located on the northern coast of Colombia, very close to the first big deposit of natural gas and connected to the deposit through a coastal pipeline, the conversion to CNG was most advanced in Barranquila. (See Figure 6.)

Figure 6: Layout of the first gas pipeline planned in the early 1990s to connect Ballena deposit in Guajira with Barranquilla and other coastal cities.

Given that Colombia has substantial natural gas reserves, the government encouraged conversion of motor vehicles to CNG. However, Colombia was also an exporter of

petroleum, and although the country experienced a drop in petroleum production during the 1990s, it was able to improve security measures and increase drilling activity to the point that the country was able to continue to export petroleum (Bureau of Western Hemispheric Affairs 2006). As a result, the government encouraged CNG conversion, but it did not heavily incentivize conversion to CNG over diesel. In cities close to natural gas resources such as Barranquila, conversion tended toward CNG, but in much of the rest of the country the conversion from gasoline followed the path of least technological resistance toward diesel, a process that was so extensive that it became known as dieselization (See Figure 7; cut Table 1 as irrelevant.) As a result, by the time that the Transmilenio Project was under construction in the late 1990s, the general trend was toward diesel (Rodríguez 2002, Yepes 2004).

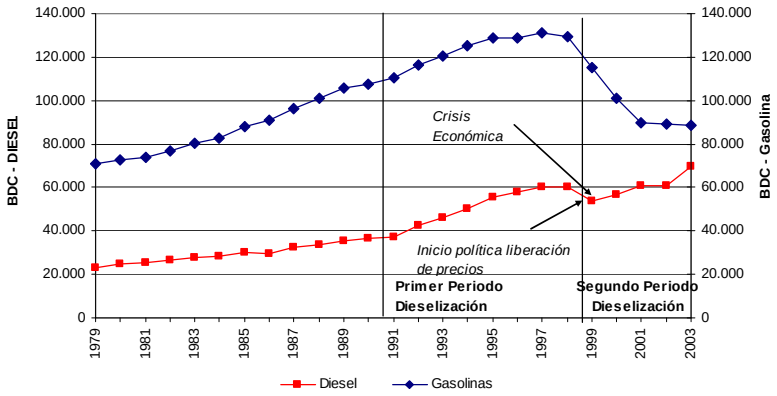

Figure 7: Dieselization of public transportation in Colombia and the relation with the liberalization of gasoline prices. BDC stands for Daily Barrels Consumed (Barriles Diarios Consumidos)

By 2006 the CNG option was becoming more attractive, because petroleum prices had surpassed $60 per barrel and concerns with peak oil were mounting, both at global level and in Colombia. As Juan Baquero, a mechanical engineer with over thirty years of experience investing in transportation projects, explained:

> If Colombia had consumed more CNG, we would have been able to produce enough diesel for the country's needs, and we would even be able to export a surplus. Instead, today the whole country is extensively consuming diesel. Not only do we have to use all the local production, but we also have to import diesel at international prices. As a result we are losing money (Interviewee #1).

Had the national government defined CNG as a national energy priority during the 1990s, the Transmilenio Project might have built CNG into the project specifications based on national energy priority incentives. Instead, the contracts were set up to allow the bus companies to choose between CNG and diesel (Transmilenio 2000). The contract also specified that the city of Bogotá was free from any responsibility in the event of failure of the bus technology. By failing to provide a clear preference for CNG on health or environmental grounds, and by shifting the risk of system failure (both in a technological and economic sense) onto the bus companies, the city set the stage for a choice in favor of diesel.

Risk and Diesel

The system designers for Transmilenio faced a number of problems that clearly shifted preferences toward diesel. First, they argued that the Barranquilla experience was not relevant because Bogotá has a significantly different environment. Due to the city's high altitude (2,600 meters above sea level), the air has 21% less oxygen. As Ricardo Wagner, a mechanical engineer with 35 years of experience in the field, explained, "There was no experience in the world with a fleet of those features at the height of Bogotá" (Interviewee #10). At the time no articulated, two-body bus with a capacity for 160 passengers had successfully operated in a city with the environmental features of Bogotá, not even in Mexico City, which is similar in altitude and other conditions. The engineers were skeptical using Bogotá as a test field for CNG technology at a high altitude. As Jaime Loboguerrero--a mechanical engineer, professor, and entrepreneur with more than thirty years of experience--commented, "The Third World is always experimenting and paying the costs for others to benefit. We said, "No," we can't allow CNG to be the option" (Interviewee #4).

More generally, there was concern that switching to an unproven technology, at least in the high-altitude environment, could wreak havoc on a complex urban transportation system and jeopardize the credibility of the Transmilenio project, which was incredibly fragile at the moment. The change might also undermine attempts to replace the existing system, which was functional even though it was chaotic and corrupt. As Juan Carlos Díaz, the first engineer involved in the project, commented:

> The system has to be reliable. In a mass transportation system that serves a city like Bogotá, with six or seven million inhabitants, it can't be so fragile that it would stop at any given moment. That would generate a problem of public order that would threaten the functioning of the city (Interviewee #2).

Another consideration that favored the selection of diesel was the scale of the change in a short period of time. Given the size of the purchase, the contractors faced difficulties even when attempting to buy diesel buses. For example, when attempting to buy a fleet of articulated buses in Brazil, contractors found that the normal production quantity in 1999 was only eight buses per year. The required number of new buses for the year 2000 was 450, and the contractor who contacted the Brazilian companies had the responsibility of acquiring 160 functioning units (Interviewee #5). To shift to CNG, which had a much smaller market, would have only magnified the problem of acquiring the needed quantity within the planned schedule.

Due to the lower levels of production of CNG buses in comparison with diesel, the up-front costs of the buses were higher. As a result, in order to be attractive the CNG buses had to compensate by providing lower operating costs. One of the key factors in determining operating costs was maintenance levels. As Juan Carlos Díaz commented: "The CNG providers argued that it was more economical, that maintenance was less expensive, and that the engines would last longer" (Interviewee #2). Although the CNG manufacturers insisted that maintenance was lower for their buses than diesel, the experience of Brazilian agencies that had experimented with CNG technology suggested that the CNG buses might also have higher breakdown rates. Víctor Raúl Martínez, the

CEO of Si99, the largest and first contractor for Transmilenio, stated that a Brazilian colleague reported that failure events were higher for CNG:

> The amount of failure events of sixty CNG vehicles compared with another sixty diesel vehicles in the same route was much higher, making maintenance costs higher for CNG...Overall, the operating costs were also higher for CNG (Interviewee #5).

In 1999 Colombia banks were unwilling to lend money to contractors that won the public competition, and consequently Si99 ended up obtaining financing from Brazilian banks. As a result, the negative Brazilian experience with the maintenance for CNG buses was especially important.

In short, a mixture of technical and financial considerations created a widespread sense of risk among the various engineers and bus companies involved in the system design and the resolution of the CNG versus diesel choice, in the wake of a major and unprecedented change in urban transportation in the city. Although the controversy was resolved by 1999, it may be reopened in the future. Between 2000 and 2006 there were some experiments with small CNG buses in Bogotá, and there is a plan to test a fleet of sixty CNG buses between 2006 and 2008. Furthermore, during the next few years a new CNG-powered bus rapid transit system in Lima, Peru, will begin operations. Colombia is also slowly deregulating diesel prices, so the price of diesel fuel is rising relative to CNG. A convergence of factors may trigger a reevaluation of diesel in Bogotá. Furthermore, the system is set up to allow for experimentation and to provide for ongoing turnover of buses, so it possesses the resilience that may allow it to overcome past mistakes, that is, if the diesel choice ends up being viewed retrospectively as a mistake (Newman 2005). Put it another way, the constellation of factors that configured the choice of diesel as the least risky in 1999 is changing and by 2008, when all buses of the first phase have to be renewed, a new constellation of factors might tilt the balance in favor of CNG.

Discussion and Conclusions

The CNG-versus-diesel controversy in Colombia articulated two different types of risk. At the outset, we noted that a city council member defined the problem as choosing the bus design and fuel that produces the lowest amount of pollution, regardless of costs. Such a perspective articulated risk from the general public perspective of the health and environmental impact of bus emissions. The approach is consistent with the precautionary principle in the sense that it emphasizes adopting the safest technology in face of known and unknown health risks from bus emissions.

However, if we follow the city's contracts, the city did not stipulate that the contractors develop a system that generates the lowest level of health and environmental risk. Rather, the contracts did much the opposite: they left the decision over fuel and bus technology up to the contractors and also shifted technological and financial risk onto them. From the perspective of the engineers and managers who designed the system, there was too much risk of technological and financial failure to warrant a shift to CNG, even if it was the cleaner fuel option at the time. If the private-sector partners were going to make the shift to CNG, they would have to absorb the projected higher costs

and risk of failure. As Víctor Raúl Martínez, the CEO of Si99, commented, "There is a fundamental unanswered question: if CNG vehicles are more expensive, and their operation and maintenance costs are also higher, who is going to pay for the higher costs?" (Interviewee #5). Because the city government did not specify that it wanted a targeted level of emissions reductions, the issue of which technology was the cleanest disappeared from the system design decision-making process. It is not entirely clear why the city government did not specify a high level of emissions reduction for the new system. Our most plausible explanation is that at the time that the contracts were issued, environmental concerns were less prominent among policymakers than they are today, and the greater public health risk associated with transportation was perceived to be accidents and fatalities.

One general conclusion that we draw from this case study is that if a government wishes to privilege cleaner air and the health of its people, then it cannot demand of its private partners that first they select the least polluting technology and second that they absorb the cost and risk premium of the least polluting technology. Such a circumstance invites the private sector partners to justify the least risky and most profitably technology as also environmentally acceptable. In other words, those contractual conditions invite the private-sector partners to translate risk from the public risk of air pollution to the private-sector risk of short- and long-term returns on investment. Instead, the government needs to establish health and environmental standards as part of its system design specifications (such as clearly mandating acceptable emissions levels for new buses), and then it needs to set up contracts with the private partners so that the costs associated with the technological and financial risks that arise in implementing a technological system that meets the standards are passed back to the users and/or government.

Under this ideal scenario, the government sets the standards for the technological system, and the private-sector firms make the technical decisions about which technologies present the lowest technical and financial risk toward achieving the standards. However, we suggest that the ideal division of labor between the public-sector agency and private-sector contractor is not as easy to implement as might first appear. Unfortunately, the decision about which technology is optimal is far from simple. The CNG firms claimed that their technology was cleaner, but from a technical and operational perspective the emissions issue was very complicated. As Jaime Loboguerrero, one of the engineers in charge of testing the vehicles, pointed out:

> CNG engines have a very good range of operation when correctly calibrated. Under those circumstances they contaminate the air less than diesel. Conversely, diesel engines that are correctly calibrated pollute less than CNG engines that are not properly calibrated. Furthermore, diesel engines are more forgiving of calibration errors than CNG engines (Interviewee #4).

Because the technical issue of selecting the optimal system that meets a public standard for acceptable pollution is itself unresolved, the city government is not able simply to solve the problem of risk by defining an acceptable level of public risk (in the form of emissions standards) and then leaving the technical decision of implementation up to the experts. Instead, where the technology is complicated, in flux, or in a state of controversy, the city government may also need to intervene in the technical

controversy by mandating at least some design features for the system. That is exactly what happened in the case of Transmilenio. Aware that the choice was going toward diesel, the city government added a contract provision that stipulated that the new buses must have catalytic converters. However, the decision immediately became part of the technological controversy. In Colombia the sulfur content of diesel is about 3000 ppm, whereas Euro 2 diesel engines are designed for 500ppm, and Euro 3 engines for 50ppm (Interviewee #10). As Víctor Raúl Martínez, the CEO of Si99, commented,

> I remember that there was a disagreement between the president of Mercedes-Benz and the head of the Environmental Agency of Bogotá (DAMA) regarding the contractual requirement that mandated catalytic converters in the buses. Mercedes-Benz, Scania, Volvo, and other manufacturers have their own laboratories that do precise and reliable tests. They argued that to install catalytic converters in buses with engines at a Euro 2 standard and with a fuel that had more than 600ppm of sulfur was useless. We finally installed the converters, but we do not think that it really helped in any way...Instead of requiring all buses to have a catalytic converter, we feel it would be better to ask the Colombia Petroleum Company (ECOPETROL) to produce better diesel by upgrading the refinery in Cartagena or elsewhere (Interviewee #5).

Although the city government appeared to fail by mandating the use of catalytic converters rather than both catalytic converters and ultra-low sulfur diesel fuel, we suggest that it was actually on the right track. A consistent approach to the negotiation of public and private conceptions of risk would need to involve two stages: first, define an acceptable level of pollution, and second, determine what technologies are needed to meet the standard (e.g., particulate traps, catalytic converters, low-sulfur diesel, or even a non-diesel fuel such as CNG) rather than leave the second part of the decision up to the private-sector partners. The city of Bogotá's Environmental Agency only failed to the extent that it did not understand the complexity of the interface between the design of the technology and environmental risk. Yet, in situations where the experts are not able to agree or may be biased in favor of existing systems, the public partner needs to step in and take a position on the technological controversy. It cannot simply draw the line at acceptable air quality or emissions standards and then shift the resolution of the technology to the system designers and contractors. It needs to be able to articulate both an acceptable standard of air quality and an acceptable technological system that meets that goal. Once the two standards are articulated, the private-sector partners can come back with proposals that provide the desired capital and services based on their assessments of the financial and technological risks that the mandated technological system requires.

Interviewees:

[1] Baquero, Juan. Mechanical Engineer. Investor in transportation projects. February 9, 2006. Bogotá, Colombia.

[2] Díaz, Juan Carlos. Civil Engineer. He participated in the design of Transmilenio 1998-99. September 2, 2005, Bogotá, Colombia

[3] Lleras, Germán. Civil Engineer and Expert in Transportation Engineering; Consultant for Steer, Davies & Gleeve. He participated in the design of Transmilenio 1998-99. June 10, 2005, Bogotá, Colombia.

[4] Loboguerrero, Jaime. Mechanical Engineer. He was in charge of the official tests done to 22 vehicles in 1999 for the Transmielnio Project. September 16, 2005, Bogotá, Colombia.

[5] Martinez, Víctor Raul. Metal-mechanical Engineer, CEO of Si99, the biggest operator of Transmilenio. September 22, 2005, Bogotá, Colombia.

[6] Noero, Juan Ricardo. Civil Engineer, current Vice Minister of Transportation in charge of seven projects of BRTs in the country: Barranquilla, Bucaramanga, Cartagena, Cali, Medellín, Pereira-Dos Quebradas and the subsequent phases of Transmilenio in Bogotá. October 1, 2005, Bogotá, Colombia

[7] Peñalosa, Enrique. Economist and historian with a long career in private consultancy. Major of Bogotá, 1998-2000. He is recognized as the father of Transmilenio. September 29, 2005, Bogotá, Colombia.

[8] Prada, Alfonso. Lawyer, Member of the City Council of Bogotá. September 26, 2005, Bogotá, Colombia.

[9] Rojas, Néstor. Chemical Engineer, expert in air contamination and particulate material in diesel. September 15, 2005, Bogotá, Colombia.

[10] Wagner, Ricardo. General Motors, Colmotores, Colombia. Mechanical Engineer with 35 years of experience in the design and adaptation of diesel engines for trucks and buses in Colombia. April 5, 2005, Bogotá, Colombia.

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Urban transport systems and STS (2008)

Valderrama A. and Jørgensen U. (2008) "Urban transportation systems in Bogotá and Copenhagen: An approach from STS", in **Journal of Built Environment** 34 (2).

In this paper, we explore the sociotechnical dynamics of developing new urban transportation systems. Based on the analysis of empirical material from the study of the Transmilenio in Bogotá and the Metro in Copenhagen, we propose that the design, construction and operation of urban transportation systems constitute a process where the actors involved negotiate and actively distribute agency in the components of the new system. The character and outcome of this process play a role in the stabilization of the system over time. Additionally, this process takes place in a setting dominated by established actors: institutions, technologies and interest groups. We analyse this setting as an arena of development, a concept that provides a framework to account for the interaction of existing and new systems. Our approach is based on theoretical developments from Science and Technology Studies, especially Actor Network Theory and Large Technological Systems, and contributes to the current research on the dynamics of change and permanence in built environments.

Urban transportations systems in Bogotá and Copenhagen:
An approach from STS

Andrés Valderrama
Ulrik Jørgensen

Department of Manufacturing Engineering and Management
Technical University of Denmark

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Abstract

In this paper we explore the sociotechnical dynamics of developing new urban transportation systems. Based on the analysis of empirical material from the study of the Transmilenio in Bogotá and the Metro in Copenhagen, we propose that the design, construction and operation of urban transportation systems constitute a process where the actors involved negotiate and actively *distribute agency* in the components of the new system. The character and outcome of this process play a role in the stabilization of the system over time. Additionally, this process takes place in a setting dominated by established actors: institutions, technologies and interest groups. We analyze this setting as an *arena of development*, a concept that provides a framework to account for the interaction of existing and new systems. Our approach is based on theoretical developments from Science and Technology Studies, especially Actor Network Theory and Large Technological Systems, and contributes to the current research on the dynamics of change and permanence in built environments.

Introduction

This article addresses a number of issues that are often unrelated in the study of transport systems, but which are crucial to success and failure of the conception, design, construction and operation of new transportation systems in cities. In particular, we discuss the dynamics and consequences of the negotiations of configurational aspects of technological systems, and the impacts of new projects in a setting of existing urban transportation technologies. We develop our discussion through the analysis of two case studies: The Transmilenio in Bogotá, Colombia, and the Metro in Copenhagen, Denmark. These cases are chosen to provide the basis for an analysis of the processes of change and to illustrate ways to overcome the dominance of existing transport systems,

both in the structure of cities and in the practices of people living in and near the city. Although the two cases are different, as are their political and economic contexts, we, however, focus on the processes of continuity and change in the interaction between transport systems and city development. The administrations of both cities undertook large public transportation developments during the late 1990s and the beginning of this century. The research on these cases contributes to a better understanding of urban transformation processes without using any a priori differences to explain the decisions involved (Graham and Marvin, 2001: 35).

We base our analysis on two main theories of sociotechnical change: Large Technological Systems and Actor Network Theory. A tradition from the History of Technology has conceptualised technologies as Large Technological Systems (Hughes, 1993, 1998; Mayntz and Hughes, 1988; Summerton 1992; Summerton and Berner, 2003). Such systems comprise an interwoven network of technologies, institutions and practices, constructed over time, which exhibit resistance to change, also conceptualized as obduracy (Hommels, 2005) and momentum (Hughes, 1993). We find the system metaphor useful and inspiring, especially to describe and understand the sociotechnical embeddedness of transport systems within their institutional configuration. However, the majority of the case studies within this tradition have concentrated on examining the internal dynamics of the evolution of one technology (like automobiles) as a dominant means of transportation, underestimating the issue of how different technologies co-exist and interact. Moreover, only few studies have focused on the process of destabilization of existing systems, and the ways to produce change through the introduction of new transport infrastructures.

To improve our understanding of these aspects, we turn to Actor Network Theory (Akrich, 1992; Latour, 1996, 2005; Law, 1991; Law and Hassard, 1999). This theory conceptualizes technologies as networks of actants. Actants are human and non-human and their interaction constitutes the sociotechnical dynamics to be accounted for. Unlike systems, actor-networks do not have boundaries and are not defined by a centre of control or a core that provides direction. Focusing on the relations of actants provides the opportunity to account for the contingent, unstable and ambiguous nature of the relationships between the relevant actants. In this theory, the destabilization of existing technological systems may often be seen as the result of something more than simply a competition of the new against the established systems. The process is rather the outcome of an interaction, where features of the existing systems (or actor-networks) are problematized (Callon, 1991), and thus, the set of relations among actants maintaining the system together are weakened.

In the present paper, we use two concepts to account for these dynamics: distribution of agency and arenas of development. Both concepts are inspired by and built on Actor Network Theory and will be defined in detail in the following sections. The first concept, distribution of agency (Law, 2002; Harbers, 2005), serves to account for how the configurational aspects, the very technical decisions, play a role in the fate of the new system and are strongly related to the existing systems. The manner in which agency is distributed among the actants is crucial in stabilizing new transport systems. In the design phase, agency may be distributed to certain parts of the system - either material entities or legal agreements or institutional design -, but these assignments have

to become part of the networks stabilizing the new technological system in its operational phase. They are, however, never completely stable and may lead to new processes of destabilization or to the construction of new – at least temporarily – working technological systems.

The second concept, arenas of development (Jørgensen and Sørensen, 2002; Jørgensen and Strunge, 2002), contributes to the understanding of how new and existing technologies are related as a whole. Infrastructures and not least the city's transport system are crucial for shaping the city structure, the distribution of activities, and the economies of city practices. As such, they are major improvements to cities and their potential for expansion depends on massive investments, because these transport infrastructures sometimes become a key part of major transformations of the city (as in the cases considered in this paper). But these transformations are not just ongoing, continuous and smoothly planned processes but are actually very expensive and politically controversial. As the existing infrastructure in most cities is not easily transformed, more radical changes in transport infrastructure often also involve broader visions of the future of the city.

The main contribution of this paper is the presentation of a framework to account for the interdependent relations between political visions and controversies, concepts related to mobility and urban design, the engineering aspects of transport design, and the actual construction of the systems. In other words, this paper reveals how the transformations are both constituent and resulting parts of the ongoing sociotechnical dynamics of the cities. The concept of arenas of development, which builds on actor network theory, is included in this framework in order to cater for the conflicts and changes in meaning among the existing and new configurations of actor-networks involved in city transport systems development.

The study of the planning and design process of Transmilenio in Bogotá and the Metro in Copenhagen is part of an on-going research project developed at the Technical University of Denmark. The research is based on the analysis of technical documents, organizational archives and semi-structured and structured interviews with designers, engineers, planners, managers, politicians and other stakeholders, and also the sparse secondary literature that exists on these cases.

In the following, we present: first, a brief description of the cases; second, a discussion of how an inscribed and practiced distribution of agency supports the stabilization of new systems, based on an analysis of the selection of the high platform as a design feature in Transmilenio, and the selection of driverless automated trains for the Metro; third, a discussion of how the traffic layout of both systems in their respective cities is the result of the controversies and formed alliances in the arenas of development in the two cases; and finally, a concluding discussion connecting our findings to the question of continuity and change in urban technological systems.

The cases in brief

The Transmilenio and the Metro were selected as key cases, because they both have global relevance: they are both well-known technologies that re-arranged in novel ways become notable innovations (Edgerton, 2006). The Transmilenio in Bogotá, has become the first Bus Rapid Transit system to achieve mass transport performances that before were only possible with heavy rail systems (Hensher, 2007). It was inspired by developments in Curitiba, Brazil, which is also a BRT, but not one that moves as many passengers as Transmilenio in Bogotá. The Metro in Copenhagen exhibits a configuration of the classic underground rail system, but without operators on board the trains, which makes it unique compared to similar projects around the world (Briginshaw, 2004). The Docklands Light Railway in London and other systems operate with no driver but a steward on board, while the Copenhagen Metro has no driver or steward on board at all.

The Transmilenio began operating on the 12 December 2000. Within the first months, this arrangement of buses, dedicated lanes, stations and a new institutional arrangement provided Bogotá with an efficient, high profile public transportation system, which in its first phase transported 790,000 passengers a day, approximately 12% of the city's total. This development provided the city with 42 km of primary roads dedicated to bus-only traffic and managed by a single institution. This organizational unity was a novelty because the previous system was distributed among many bus companies and bus owners operating many superimposed routes, which resulted in an excessive number of vehicles clogging the streets and competing for passengers (Ardila-Gómez, 2004). Bogotá had around 7 million inhabitants in 2000, and less than 15% of the city's population could afford a car; and it is still the only highly populated capital in Latin America that has not built a rail system to procure public transportation.

On 19 October 2002, the first new Metro line began operating in Copenhagen, connecting the centre of the city with the island of Amager, where Copenhagen International Airport is located. The development of this transportation system was part of an urban development project, which followed the adoption of a central growth scheme for the city that aimed at creating 100,000 new jobs. The central growth scheme replaced the earlier suburban growth schemes for the greater Copenhagen area, known as the 'finger-plan', which was outlined in the city development plan of 1947. The core case of the central growth scheme was a 'new-town' development called Ørestaden and the Metro is the fast link from this new area to central Copenhagen. The building of the Metro, together with other infrastructure projects, is being financed by selling land to companies settling in the area. The Metro was seen as a new type of urban transportation, delivering what was called a 'high-end' means of transport, intended to lure car owners and business people over to public transport and thereby relieving central Copenhagen from increases in car traffic resulting in congestion in the inner city and on the bridges crossing the harbour to and from Amager (Frederiksen, 1996; Munch and Jørgensen, 2001). The Greater Copenhagen Area, comprising Copenhagen, Frederiksberg and several other municipalities, has approx. 1.7 million inhabitants.

Distribution of Agency

We propose that it is helpful to view the design of urban transportation systems as a process where the actors involved negotiate and actively distribute agency in the components of the new system. The character and outcome of this process plays a role in the stability of the system in time. The distribution of agency is a concept that has been coined within Actor Network Theory (Law, 2002; Harbers, 2005). The term relates to the agency of human and non-human actors within a network of relations. In other words, it relates to the capacity of both human actors (such as designers, operators and institutions, among many others) and non-human actors (like hardware, software, buildings, roads etc.) to enable, resist, conduct, guide and perform action within the life of a system. We discuss and illustrate this concept further by examining two aspects of design in our case studies: In the Transmilenio case, we trace how designers, investors and politicians decided on a high platform, integrated bus system; in the Metro case, we discuss how the decision was made to build and operate driverless trains.

Transmilenio: High or Low Platform

Figure 1

Ardila-Gómez (2004) provides one account of how the planners, the would-be concessionaries and Mayor Enrique Peñaloza were to decide whether the whole bus system should use high or low platform buses. No agreement existed among the relevant groups that were participating in the negotiations nor did the international literature provide elements to help decide which was better. Although one consideration was that the market price for low platform buses was from US$ 10,000 to US$ 20,000 cheaper, it was also the case that an order for 450 buses for the first phase of Transmilenio would minimize the difference in cost. The Mayor and the planners wanted high platform buses with doors in the left side of the bus to differentiate them from the existing buses with doors on the right side and access at street level (Figures 1 and 2). They sought to ensure that old buses could not use the new roads and the new Transmilenio stations, and also that the new Transmilenio buses could not leave the dedicated lanes and pick up passengers on the sidewalk. The would-be concessionaries preferred low platform buses, also because they thought they could re-sell them to other cities when their service in Bogotá was terminated. The planning team and the Mayor left the last word to the would-be concessionaries, which were going to purchase, operate and run the buses and take the financial and technical risks. After a heated debate, they finally decided to

choose high platform buses with doors on the left side as initially suggested by the Mayor and the planning team.

Three aspects of the process described above are worth discussing: first, who is involved in the design of the system; second, what is being discussed; and third, the role the process to make this decision plays in the re-configuration of actors. The discussion is carried out between three main actors: the Mayor of Bogotá at that time, Enrique Peñalosa, for whom The Transmilenio was a pet project; the planning team; and the would-be concessionaries. The latter actor comprised a group of owners of established bus companies that had been invited to participate in the process by the Mayor and his planning team. This decision was already the outcome of some tough bargaining between the planning team and the Mayor. The Mayor wanted an efficient new system that would run even if it meant the replacement of the operators of that time, while the head of the planning team, Ignacio de Guzman, insisted that a more inclusive approach with the existing bus operators would guarantee a successful transition. Therefore, we can say that already in the composition of the members of the institutional core of the Transmilenio system negotiations were taking place regarding both their power to decide, which is the subject of interest in this section, and of the power balance in the arena of development, which we discuss in the next section.

Figure 2

The red buses of Transmilenio run in separated lanes in the centre of the road. Each bus has four sets of doors on the left side of the vehicle. The high platform buses stop at high platform stations, where boarding is performed in a very short interval of time, as in rail systems. This is possible because passengers pay when entering the stations, not the buses, as in rail systems. Each bus can carry up to 160 passengers. Pictures provided by Transmilenio S.A.

Note that this interaction takes place on the basis of a technical feature of the new system. Thus, this discussion is also political, because the Mayor and the planning team are trying to design a new system that is radically different from the previous system. The high platform is preferable because it can best insulate the new system from the old. However, the high platform cannot work alone, since it is not enough to configure the new vehicles; it is of strategic importance to include the existing transportation companies in the design in order to support the differentiation between the old and the new because it is expected that they will also take responsibility for the removal of old vehicles from service. Therefore, the old vehicles have to be re-configured; two strategies are devised for this: first, dismantling some of them (in the first phase, 2.5 old buses had to be taken out of drift for every new vehicle); and second, moving the existing old buses that would continue servicing the city to other corridors. In short, the high platform solution is part of a distribution of agency, which also includes the selection of relevant actors and the re-configuration of other existing systems, with the aim of insulating the new and the old system from each other. This process also provides the new means of transport with an institutionally and technically supported momentum from the very beginning, as explained in the next section.

The decision process itself is also important. The Mayor and the planners provide the would-be concessionaries with the last word on this issue. They finally decide to take the high platform, and thus they act according to the script (Akrich, 1992) being proposed. They accept the programme of action (Latour, 1992) described above, and at the same time, they strengthen both their commitment to the new system and the authority of the Mayor and the planning team during the process. It follows that even before it physically exists in the buses and the stations, the high platform is already starting to perform its role in the distribution of agency for the new system. That is, the decision for the high platform, the participation of the would-be concessionaries, the decision to dismantle the old buses, to place the doors on the left side of the bus, and all the institutional arrangements are intended to act in a specific way to hold the system together and make it work. However, these actants do not necessarily perform as intended, because serious trade-offs are involved. For example, the high platform played an excellent role in differentiating the city's new system from the old system. However, at the end stations, it became difficult to integrate the Transmilenio with the intercity bus services, which was also intended by the Mayor and the planners.

Metro: Un-manned trains emphasize conflicting views on risk and safety

In the detailed design of the Metro, several questions were raised concerning the safety regulations on this kind of train and the use of operators for different tasks in the running and servicing of the system. A driverless train (Figure, 3) solution was considered from the very beginning (Søndergaard, 1995; COWIconsult, 1995).

While safety issues in the public's perception – at least as interpreted by designers – were often related to the presence of an operator able to control and stop the train, several questions were raised regarding this dominant view, both in the public's perception and the point of view reflected in the standards developed for automatic train control (ATC) systems in Europe since the 1970s. Embedded in the developed standards is a great degree of mistrust toward train operators that is based on accidents caused by

overlooked stop signals – mainly defined as human errors. Following the implementation of ATC systems, operators have fewer tasks and less responsibility. In addition, in the case of high frequency metro systems, the shorter distances in time and space between trains demanded control systems and control rooms to guarantee a smooth operation. The designers of the metro were therefore forced from the very beginning to plan and install such systems and create the necessary overall train management and traffic controls, ranging from train position identifiers and regulators of the individual train's movement to central computers registering and maintaining distances, speed, station access, and the handling of malfunctions and disturbances. The over-all effect of these solutions is to reduce the role of the train operators. In short, ATC standards and the design requirements for a high frequency metro restrict the role of operators to the extent that full automation is both desirable and possible. It is important to note that trains running with high frequency were an integral part of the idea of a 'high end' means of transport, with no need for public time tables and with a short waiting time for passengers. This was an innovation in comparison to the existing suburban train system in Copenhagen which runs on fixed timetables.

Figure 3: The trains of the Metro have no driver. Passengers can enjoy the view from the very front. Picture taken by the authors.

Additionally, the cost of operating the Metro was for the developing company Ørestaden A/S very dependent on the wages of its operators. Trains constructed to be controlled by an operator are expensive and also difficult to change, which also made the unmanned solution attractive. The company was also interested in utilizing its personnel in such a manner as to optimise the anticipated safety in public view and at the same time produce most value for the company. This desire came from studies of public responses to safety issues, which demonstrated that the possibility of assaults at desolate stations and in empty trains e.g. at night was seen as more frightening than running unmanned trains. The isolated operators of the trains would not be of much use since in instances such as these they could neither improve safety in the train nor necessarily make the passengers in the train feel safer. This was at least the argument presented in the debate and decision making process. And as a result of these considerations, the tunnels were installed with lights and the trains with large windows also at each end so that passengers had a full view of the tracks and the tunnels.

Until now, the safety problems related to the operation of the Metro have turned out to be very mundane. They have been typically related to the malfunctioning of the automatic doors or system shut down caused by garbage on the rails or even birds entering the train tunnels. And because of the automatic control systems, these malfunctions often take longer to be solved, as there are no operators who can just override the computer-based decisions by direct inspection and judgement and manual operation. Also, the costs and technical problems related to the testing and documentation of the computer-based traffic control systems turned out to be very challenging, as no established procedures were available to demonstrate that the systems were fool-proof and did not have built-in control conflicts and dead-locks (Abild, 2003).

The agency delegated to the control systems and the technical elements of the system, and the lack of operators who could use their experiences and heuristics to judge and override the computer-based control decisions, may have been able to secure safe operation, but at the cost of added random shut downs and time delays to the operation. With the combination of safety and high frequency so closely linked to the automation of the trains, the control system, also in the operation of the trains, was delegated decisive power (agency). As a result, the control system turned out to be very sensitive and the employed operators were involved too little in train operations and thus not able to handle situations of stopped trains, often causing long waiting periods where people were stuck in the trains and tunnels and not even able to get out of the trains. This has in some cases led to obstructive behaviour, where people left the stopped trains and went onto the tracks in the tunnels. As a consequence, the Metro Company was forced to re-educate their operators in new ways to support the customers and avoid these situations.

While the question of driverless trains has become a non-issue from a safety perspective, the distribution of agency within the automated train system and its operators has turned out to be much more complicated than anticipated by engineers and designers. This has been detrimental to the reliability of the Metro. The potential safety problems of implementing driverless trains have been tackled successfully while new risks relating to the operations and reliability of the Metro have arisen. This demonstrates that the negotiated distributions among the actors have not yet reached their final form. Birds and doors are ‘sabotaging’ the smooth operation of the trains, since the automatic control posts are too sensitive to the obstacles, the operators at the stations are excluded from the control circuits and forced to focus on repairing malfunctioning parts that in a non-automatic system would have been unproblematic, and the customers are often left with a frustrating lack of comprehension of what is happening.

As part of the historic construction of the new Metro, its distinct features and differences from the existing suburban trains – the S-trains – were stressed as part of an attempt to make them stand out as a new and modern means of metropolitan transportation (Ørestadsselskabet, 1997). This also made the whole construction of the Metro, with its narrow tunnel width, its power supply through an extra rail (the S-trains use overhead power lines), and its un-manned and high-frequency operation, into a distinct strategy of dissociating the Metro from the rest of the suburban train network. Concerning the distribution of agency to the size and type of trains, the constructed difference is obvious, whereas with some other aspects of the design – the Metro script

of being a high-end means of transportation – some of the same differences that make it into a distinct highly automated transport system also become an obstacle to the anticipated role of the Metro as providing a high-end means of reliable transportation.

Distribution of agency: conclusion

In summary, the process of distribution of agency captures important aspects of the material micro-politics inscribed in the design of new transport systems that are often overlooked. Firstly, in both our cases, agency was distributed during the processes of design and implementation to various parts of the new systems, including their hardware, their institutional design and their operational design, as illustrated in the high platform of the Transmilenio and the automation of the Metro. Secondly, these features were not only influenced by the contingent activities of the planners, designers and politicians involved, but were also related to previous practices. For instance, the increasing demands on automatic train safety systems in Denmark played a role in the Metro. In the case of the Transmilenio, improved road safety was influential. Thirdly, both cases illustrate the emphasis placed by designers on making the new systems different and independent of the existing ones: the high platform in Bogotá and the automation in Copenhagen make the new systems completely incompatible with the old ones. And finally, these design features do not act alone. The agency in both cases was dependent on how the material scripts (Akrich, 1992) perform in relation to other elements – e.g. whether the institutional configuration of the operators supports the discontinuity between the new and the old. The agency inscribed in the design phase did not make the high platform and the automation independent actants on their own just performing as intended. Both the high platform of the Transmilenio and the automation of the Metro contribute to the realization of these systems, but also pose new problems to their working and may have even influenced their relation to the existing systems. To further explore these types of interaction among the new and the established systems, we now turn to the concept of arenas of development.

Arenas of Development

A city can be conceived of as an arena of development, populated by a set of entrenched technologies (Sørensen, 1993) of transport and different neighbourhoods with their specific historic compositions of building, institutions, leisure and business activities, all originating from different periods of city expansion and re-construction. The arena concept has been elaborated by Jørgensen and Sørensen (2002) and Jørgensen and Strunge (2002). In this section of the paper, we intend to use the concept to account for the dynamics of the new actor-networks in arenas already dominated by others. Thus, the concept of an arena of development is a further elaboration of actor network theory which accounts for the relations between new and pre-existing actor networks. These relations are to do with configuring boundaries, inter-operations, and conflicts between the different transport systems. In other words, cities can be considered to be constituted by different systems that compete, complement and interrelate to facilitate transport (trains, buses, bicycles, cars and pedestrians in Copenhagen; buses of very different sizes, cars, bicycles and pedestrians in Bogotá), binding together both people's distributed activities and the different parts of the city, as well as separating people: the systems configure space. When a new system enters this populated arena of

development, re-configurations take place and interactions may evolve that either support or counter the political programmes, anticipated impacts, and designed scripts of all the actors.

This approach has as its focus the intervention in the arena based on establishing presence and performing strategies of recruiting some new actors and marginalizing other existing actors, and transforming them into allies within the configuration of the new transport systems. These processes involve creating and stabilizing new alliances as well as out-performing others. To demonstrate this analytical approach and show how actions perform in achieving such transformations, we describe and discuss the decision-making processes in relation to the routes of the Transmilenio in Bogotá and the Metro in Copenhagen.

Transmilenio: Bus Lanes and Traffic Layout

According to Ardila-Gómez's (2004) account, in 1998 during the planning of the Transmilenio, designers reached the point where they had a clear idea of the corridors that should be built in order to have a comprehensive system for Bogotá by 2016, with no point of the city further than 500 meters from a bus station. However, since the whole system could not be developed at once, they faced the challenge of dividing the development into different phases. In other words, they had to decide where to start. The planners proposed tackling Avenida 7ma first, an important corridor, but not the biggest. The Mayor, however, wanted to build the Avenida Caracas first, which was the most representative corridor in symbolic and practical terms, as it was (and still is) the backbone of the road system of Bogotá (Figure 3). It was also the corridor that carried the biggest load of passengers and was thus much sought after by both old and new operators. Planners suggested a conservative strategy that first tackled the Avenida 7ma as an experiment to prove to the citizens that the new system was better than the old one. But the Mayor argued that building the Avenida Caracas was appropriate for various reasons: firstly, he was willing to spend the political capital necessary for this corridor; secondly, there was no guarantee that the subsequent Mayor would extend the system to this corridor, even if the experiment on the Avenida 7ma was successful; thirdly, he believed that tackling the biggest corridor provided the system with greater strength; and fourthly, whereas the Avenida 7ma served mainly middle and upper class neighbourhoods, the Avenida Caracas ran through all kinds of neighbourhood income levels, and Peñaloza wanted to secure support for the system from all these socio-economic groups (Figure 4).

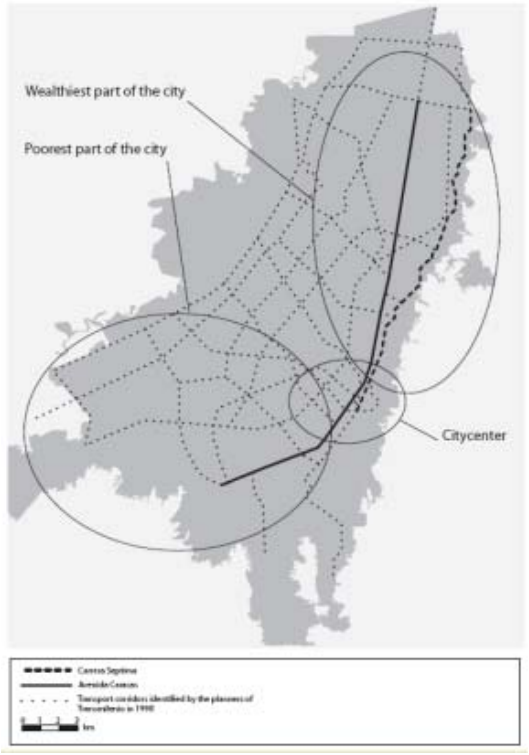

Figure 4

This account focuses mainly on the role of the planners and the Mayor as prime movers. However, we also have to consider other actants that participated in this decision. The Avenida Caracas itself had been converted in 1989 into a corridor where traffic was differentiated by being filtered into different lanes. The avenue had two pairs of lanes going in each direction: one pair for cars and another for buses only. However, the bus lanes where shared by many bus companies, which still competed for passengers among themselves. This arrangement was a technical success, because it was the first to achieve loads previously achieved only by heavy rail systems: the buses running exclusively in bus lanes could carry up to 25,000 passengers in each direction per hour. With time, however, the increasing number of buses, the lack of maintenance, and an obviously deficient urban design turned this corridor into one of the most dangerous in the city. Users regarded it as unsafe, ugly and even deadly. In short, Bogota's experiment with bus-only lanes showed that it was quite promising, technically, to maintain traffic separated in this way, but that a great effort was required to rehabilitate the corridor aesthetically and make it safe.

The would-be concessionaries also had an ambiguous position in relation to which corridor to tackle first. On the one hand, the Avenida Caracas was the big cash cow, which at that time was shared by many bus companies, more than 20. The same applied to Avenida 7ma, but on a smaller scale. The organizational design of the Transmilenio meant that only very few (two or three) companies would operate the chosen corridor. Therefore, the potential concessionaries was actually a very heterogeneous group of people and companies that was going to be re-shaped heavily by the whole process of participating in the design of the Transmilenio, partly through entering into alliances among themselves in order to compete for contracts. The process was thus loaded with uncertainty (Ardila-Gómez, 2004).

We can see how the planners, the Mayor, the existing bus lanes in the Avenida Caracas, and the heterogeneous group of potential concessionaries are all involved in a process that both depends on their actions and is going to re-shape their ability to act, and finally, their identity. The process is ambiguous, messy even, and extremely delicate. However, it illustrates how the arena of development of transportation is being reshaped in various ways: firstly, no one possesses autonomy, but all are implicated in a complex process of negotiation of their own power possibilities; secondly, in the decision-making process, their very existence and identity are at stake; and finally, the outcome will reshape not only their identity and power but the constitution of the whole arena of development of transportation in Bogotá. The outcome of this complex process was that the Avenida Caracas was selected. Both the Mayor and the planning team gained in power and recognition; the group of would-be concessionaries was reshaped, in a process which strengthened the position of some, and excluded others altogether; and the Avenida Caracas was entirely redesigned and reconstructed. The transformation of the actants constitutes the relative strength of the new system and how it reshaped the arena of development.

The process also involves the other systems or actor-networks populating the arena, and we introduce now those that are most relevant. Firstly, car use had been restricted in Bogotá since 1997; in fact, according to plate numbers, car owners are not allowed to drive during peak hours two days every week, which means that during peak hours 40% of the private cars are not in use. Secondly, for the first time in Bogotá, bicycle paths were built between 1998 and 2000 with the intention of providing space for this mode of transport in the city. And finally, all governments tried to reduce the number of conventional buses on the streets by restricting their circulation and also by using a number plate system similar to that for cars which we have just described. In this manner, one-fifth of the conventional bus and taxi fleet was prohibited from running every weekday and every Saturday. These measures were implemented to produce a balance in the arena of development in favour of public transport and bicycles. Rather than assessing the relative success of these measures, we wish to stress the fact that they are related to the re-configuration of the arena of development, and that they have an impact on the relative success of the Transmilenio as a newcomer in the arena.

Metro: Choice of Technology and Traffic Layout

Three very important perspectives were involved in the creation of what would become the Metro in Copenhagen. The first related to the basic vision of Copenhagen as a (new) metropolis and how to support its growth. This contrasted with earlier plans for a much less centralized development of Copenhagen based on the so-called finger plan, which essentially focused the city plan on suburban areas around main transport ‘arteries’ separated by green belts. With industry and institutions moving out of the city centre in the 1970s, Copenhagen, like many other large cities, experienced a decline in revenues and its ability to attract investments in the city centre. Through a sequence of government commissions investigating transport systems and re-working the role of Copenhagen from being merely a large city in Denmark to becoming the metropolis and growth pole of Denmark, a new perspective of centre growth was adopted (Tengvad, 1988; Würtzen, 1991; Ørestad Act, 1992). This led to the Ørestad plan, which was

conceived as a new town development organized as a separate, public-owned consortium (Ørestadsselskabet), where infrastructure would be financed by selling land parts of Amager Fælled (an undeveloped common close to the centre of Copenhagen) to companies, public utilities and housing projects. The new transport infrastructure aimed to support this new centre growth perspective was a core element of the Ørestad project.

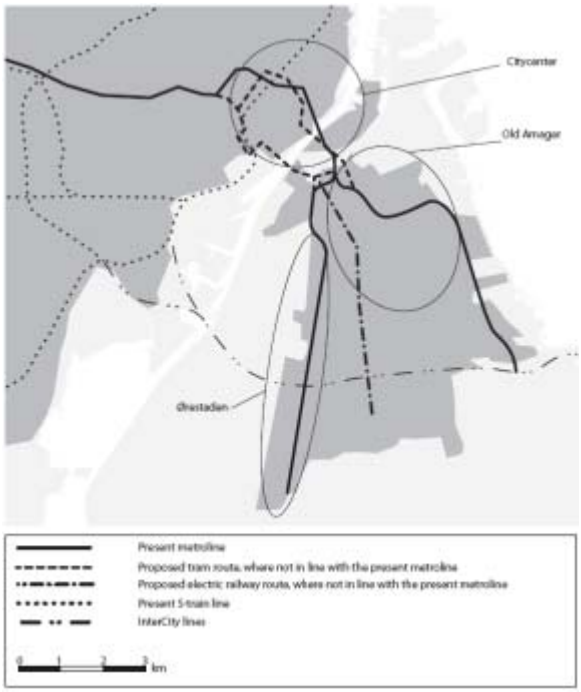

Figure 5

When the technology for the new public transport system servicing Ørestaden had to be selected, several options were discussed. Basically, three different technical solutions were presented: a driverless mini-metro, a man-operated light rail, and a man-operated tram system (Søndergaard, 1995; COWIconsult, 1995). Two types of discussion were raised: one on the efficiency of the different means of public transport in substituting transportation based on the private car, and one related to the areas of Amager to be serviced by the new system. This second debate was basically a discussion about whether the already populated Amager neighbourhoods should be given improved access to public transport or whether the new town area of Ørestaden ought to be provided with public transport even before it had the required demand. In two of the alternatives (mini-metro and light rail), tunnels were suggested which crossed the harbour into the inner city of Copenhagen, but for the traffic layout outside these areas, both systems would require elevated tracks to avoid interference with road traffic. The trams were more flexible and could operate in mixed traffic, though at the expense of speed and increased congestion.

There was a common traffic layout for all these solutions based on a route forking into two lines running on the western and the eastern side of Amager, with the eastern line being integrated into the Ørestaden project. The traffic layout was controversial, however, since people living on Amager had complained for many years about deficient public transport, based solely on bus lines in mixed traffic, and with the bottleneck

caused by only three narrow bridges connecting Amager with central Copenhagen. For several decades, plans had been made to connect Amager with the western suburbs of Copenhagen with a rail-based connection, but these were never implemented. It was hoped that the new traffic line to Amager would alleviate these problems and a number of action groups were inspired to be formed with local residents and also traffic and town planners from Copenhagen and from architectural firms to discuss these possibilities. The local residents and their supporters were all in favour of a traffic layout which placed the new public transport within Amager's existing road infrastructure, thus supporting the existing settlements. The new town planners in Ørestaden, on the other hand, were bound to a traffic layout primarily supporting the Ørestaden area – not surprising, since the whole economic foundation for the new town planning was to use the funds raised by selling the land at high prices.

The final choice was the minimetro – later renamed the Metro – due to its promising features, both functional and symbolic, and modern technology. The much touted 'high-class' and 'high frequency' features also became part of the distribution of agency of a system intended to attract car users and executives. The Metro choice was also closely connected to the traffic layout: Because the metro was the technology that needed the greatest radius for turns, it was necessary to build it underground in Amager's old neighbourhoods. Had the tram solution been chosen, the old Amager residential areas would have received a service with more stops and one better aligned with their needs. Throughout the process of making the Ørestaden project the core of the new centre growth in Copenhagen, the new town development was favoured instead of improving the infrastructure of the established districts of central Amager, a choice that would have been impossible without the support and intervention of the central government which heralded a vision of Copenhagen as a new metropolis. Alliances were made with institutions and companies that were building their future on the Ørestaden project, while the existing actor groups on Amager were excluded, along with the well established operators of the S-trains and bus lines (Skovmand, 2000).

To overcome some of the objections to the new Metro line which was to run through the new town and the still rather open and unpopulated areas of Ørestaden, another line was proposed to service the eastern side of Amager along the coastline to an end station at Copenhagen Airport. This line was intended not to be financed by the Ørestaden project, however, but the Greater Copenhagen Region instead. This line opened to the public on 28 September 2007, and it is still supposed to compensate for the exclusion of 'old' Amager from the earlier planning process.

The choices of technology and traffic layout were closely linked in the Copenhagen case. Additionally, both aspects were related to the existing entrenched technologies: car users were supposed to change to the Metro, thus reducing car congestion especially in the bottleneck areas, namely the bridges. Also, the inefficient buses would be replaced by a "high class" and "high frequency" connection. Therefore, the design of the system, the traffic layout, tunnels and stations, all constituted part of a specific distribution of agency intended to generate enough momentum to secure a re-constitution of the arena of development of transport in Copenhagen.

Arenas of development: conclusion

The two cases illustrate how difficult and how important it is to build stabilized actor networks that can re-configure the arena of development to realize the visions involved in new transport systems. Whether they become successful or not depends on their performance as well as the anti-programs (Latour, 1992) initiated by other actors. At the same time, the cases demonstrate the intertwined relation between traffic layout, transport technology and other design features. In other words, the politics of technology are at play since the specific performance of the technologies is built into features of both specific assigned properties and the building of stable and supporting actor-networks. Despite the many differences in both contexts and technologies in the cases considered here, they share a specific feature: both systems implied a sharp socio-technical differentiation from the existing transportation systems. In both cases, the distribution of agency and the re-configuration of the arena of development were actively sought by creating new institutions with sufficient resources and political support: In Copenhagen, the national and local governments created Ørestadsselskabet and in Bogotá, the city government created a new company, Transmilenio S.A. In Copenhagen, DSB and the National Railway were excluded from the institutional processes and intentionally kept from influencing the new company; and in Bogotá the new company was sharply separated from the existing transport authorities.

Perhaps this process of excluding key institutions was the preferred strategy in both cities to cope with what became a long period of 'stalemate' in transport planning, a period in which there were only modifications but no construction of large, new projects. During the 1960s and 1970s, the private car became increasingly dominant in both Copenhagen and Bogotá. The main ideas involved in city planning were meant to create systems of transport based on the co-existence of different means of transport by introducing broader roads, highways, and in several cases also systems of traffic differentiation. But already in the 1970s, these new planning approaches and their support in statistical transport models and road planning were in crisis. In Copenhagen, city planners and other experts sought to stop highway projects from penetrating city centres and would even participate in public protests. These efforts rendered the planning visions and their support in theories and models obsolete (Elzen, 2001; Frederiksen 1995; Hughes, 1999); and in Bogotá, transport planners actively promoted bus solutions and restrictions in car usage, and resisted the development of expensive metros (Ardila-Gómez, 2004). In addition, both Bogotá and Copenhagen developed a state dominated by separate planning institutions responsible for roads, public transports, and city development, but without integration. Part of this 'stalemate' situation was supported by the lack of vision for city development and the confrontation between antagonistic actors. The problems of the entrenched transport system were mirrored in the lack of an overall vision or base for new strategies.

Conclusions

Through an analysis of the Transmilenio in Bogotá and the Metro in Copenhagen, we have examined some aspects of how new transportation systems are designed, built and operated in cities. Cities, at any point in time, operate with a set of technologies, institutions and practices for transport, which we have characterized as a set of pre-existing entrenched technologies (Sørensen, 1993). We state that in the social and material process of change, two aspects deserve attention: The first has to do with how the physical and organizational design of the new system plays a role in the system's success and stability, and we describe this process by using the concept of distribution of agency. Simultaneously, we stated that the design process is related to the pre-existing entrenched technologies. Thus, the second aspect has to do with that this interaction influences the final design, and we propose the concept of arenas of development to account for this interaction.

In the process of design, we explain how the main stockholders in both cases (planners, politicians and technical experts) sought to establish specific physical features in the new system. These features were not only technically appropriate (high platform, automated trains), but they were also expected to play a role in the stabilization of the system. In other words, agency was distributed to these physical features and to other parts of the system. It was expected that they would perform as intended and, in collaboration with other organizational and physical features they would render the system durable. These design decisions, however, did not originate solely from the desks of the experts but were partially defined by the existing entrenched technologies in their respective cities.

Therefore, the high platform in Bogotá was also selected partly to insulate the new system from the existing ones, and the automatic trains in Copenhagen were chosen as part of a general effort to make the Metro an independent transport system. In both cases, these technical decisions were influenced by the existence of an entrenched system of buses in Bogotá and an entrenched system of suburban trains in Copenhagen. In addition, in both cities, the definition of the physical routes of both systems were carefully considered, discussed and defined in relation to their role in the distribution of agency as mentioned above. We used the concept of arenas of development to describe this interaction between the new transport system and the existing ones. We also stated that the outcome of this process would redefine the balance of power among the new set of technologies, changing the relative weight or momentum of each one and the arena as a whole.

In a nutshell, our argument is that old and new systems, or rather, actor-networks, seek actively to distribute agency in order to create momentum and to build a sustainable space for the new transport technology in their arena of development. However, the creation of a new technological system is not enough to conquer the whole transport arena, due to the diversification of means, functions and expectations built into each of the already existing technologies. Therefore, the process of assigning agency and building momentum, which is highly political and technical at the same time, implies that from layout definition and the choice of technology, down to specific hardware and

organizational decisions, actors are struggling within the existing arena and determining the stability of the new order.

We propose that our argument has consequences for at least four research issues: first, change and permanence in urban infrastructures and cities; second, the conceptualization of space in cities; third, the role of technocratic discourses; and fourth, the framing and staging of change.

Hommels (2005) has sought to explain change and permanence in urban infrastructures using the concept of obduracy. She proposes three explanatory mechanisms to account for the subtle ways in which buildings, networks and urban infrastructures remain the same over time: first, obduracy as dominant frames relates to how prevailing paradigms, mental models or technological frameworks prevent radical change; second, obduracy as embeddedness of a given object in a set of relations that fix it; and third, obduracy as persistent traditions or how the momentum of urban infrastructures contributes to holding them in place. We believe that the analytical tools to account for obduracy should also account for change, if they aim at being symmetrical, as Hommels herself states. The concept of distribution of agency relates to her first and second concept of obduracy, revealing how specific design and organizational features play a role in the stability of infrastructures (or buildings, or networks) over time – a process that only makes sense in relation to the set of existing infrastructures or the configuration of the arena of development. Our cases illustrate that in situations where spaces of a city are reconstructed, or new transport infrastructures add, changes occur not only within the new spaces or systems but in the city at large, by re-configuring relations and providing possibilities for new ways of perceiving and making sense of the city.

Newtonian conceptions of space and time determine a common sense conception that transport systems are means to achieve mobility in a certain space, which is defined by natural principles and boundaries. Such conceptions are often found in the literature on transport systems and transport planning and translated into models of transport behaviours and needs. However, more sophisticated conceptions invert the relation and state that space is the outcome of different ways of being, affecting and organizing others (Thrift, 2006). The concepts proposed in this paper contribute to the understanding of the dynamic character of urban space and how it is re-shaped by the re-constitution of the arena of development of transport; that is, space is the outcome of the dynamics in the arena of development and not the arena itself.

Our analysis also contributes to the critique of technocratic discourses such as; the four step model (e.g. Vasconcellos, 2001; this model is still too popular, as expressed by Lay, 2005), which defines technological choices as rational among neutral options; other technophile approaches like traffic engineering, which only serve specific actor-networks within the arena; and the overrated belief that transport policies are conceived as consistent by experts but later distorted by vested interests (also currently strongly supported in the technical literature, as illustrated in Vickerman, 2005). The arena concept also brings into the analysis the fact that planning and design decisions are always taken within an existing balance of actor-networks, and that this process is accomplished collectively. This adds to recent calls for the study of cities as ensembles of organized complexity, where the public should be included in the early stages of

projects (Brand, 2005), during which the agency distribution and arena re-configuration are already being negotiated and developed.

The staging of interventions in the transport arena is crucial, and the process involves including and excluding actors and framing the new transport technologies, both institutionally and in guiding visions that order the symbolic and functional attributes of the new systems and prepare their entrance on the arena. This deliberate creation of socio-technical ensembles (or hybrids) and the process of preparing them for the political dynamics involved in the planning of transport systems include perspectives concerning the basic role of cities and how the cityscape is developed as part of the introduction of new means of transport. Thus, transport systems are given a more important role in shaping the future of cities, and at the same time, means of transport are elevated from a mere functional interpretation to include the delegation and distribution of agency and responsibilities for the future of cities.

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How do we co-produce urban transport systems and the city?

Valderrama A. (2009) “How do we co-produce urban transport systems and the city? The case of Transmilenio and Bogotá” in Bender, Thomas and Farias, Ignacio (Eds.) **Urban Assemblages: How Actor-Network Theory Changes Urban Studies**, Routledge.

In this paper, I explore the various elements that influence the decision to define specific design features in urban transport systems. By using the concept of script, I trace the dynamics that define features. This process is also influenced by readings that the actors make of the history of the arena of development for transportation in Bogotá. The resulting scripts configure a distribution of agency that constitutes the designed transport system of Transmilenio and at the same time re-configures the arena of development for transport and the city of Bogotá. During the process, the identities of the actors involved also change.

HOW DO WE CO-PRODUCE URBAN TRANSPORT SYSTEMS AND THE CITY? THE CASE OF TRANSMILENIO AND BOGOTÁ

Andrés Felipe Valderrama Pineda
Technical University of Denmark

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INTRODUCTION

This chapter addresses the question of how do we co-produce urban transport systems and the city. The first part of the question states a reflective aspect that is central to the analysis: the agent of co-production is plural and it includes a number of planners (politicians, engineers, economists, lawyers, communication experts, journalists, consultants, sociologists, historians), citizens, operators, investors *and* non-human actors *and* the author of this text among many other analysts (some of them listed in the references) (Callon 1986). The question emphasizes that the object of study is the action of co-producing: neither the city nor the transportation system pre-exists the other. In other words, it is important to avoid any analytical choice that assigns ontological precedence to either entity, which is a consideration also known as the principle of symmetry (Latour 1987). The city and the transport systems are both produced simultaneously and my task is to propose a valid description of that process. I prefer co-production to co-evolution because this last term conveys the idea that there are some distant natural causes behind the process. Additionally, the produced entities, the transport system and the city, are not bounded and single objects. They are heterogeneous, multiple and contested. And they change. And it is that change that I propose to account for with this analysis.

I will develop the analysis through a case study. I will analyse how Transmilenio and Bogotá were co-produced since 1998. These two entities are interesting because they have become popular worldwide, especially among architects, urban and transport planners and city politicians during the first years of this century. This celebrity is due in great measure to the activism of the former mayor of Bogotá, Enrique Peñalosa, who tours the world, financed by the Institute for Transportation and Development Policy

and other organizations, presenting the highlights of a transformation in which he himself played a central role (Ardila-Gómez 2004; Hidalgo and Hermann, 2004; Shane, 2006). This chapter is also a critical review of this promoted story of Transmilenio and Bogotá.

For the purposes mentioned, I will base my analysis in two main theories of the field of the Science and Technology Studies: Actor Network Theory and Large Technological Systems. These theories have been elaborated by a number of scholars to account for the dynamics of co-production of scientific knowledge, technologies and society during the last three decades. In line with other chapters of this book, I attempt to use these analytical tools to contribute to a development of a more robust field of urban studies, one that pays attention to the dynamics of knowledge and technology development as part of city life. (Graham and Marvin 2001)

TRANSMILENIO: A LARGE TECHNOLOGICAL SYSTEM

What is Transmilenio? The standard answer to this question is that Transmilenio is an urban transportation system that began operating in the city of Bogotá on the 4th of December of 2000. The system is a world innovation because it is the first bus rapid system designed for mass transit. In other words, it is the first bus system that achieves capacities which were formerly believed only heavy rail systems could provide (Ardila-Gómez 2004; Hensher 2007). The system, in technical terms, basically consists of high capacity buses that run in the middle of the road in dedicated lanes (Figure 1). These buses stop at stations that are separated between 400 and 600 meters along the city main corridors. The bus has four sets of doors on the left side which match automatic glass sliding doors at the stations allowing for passengers to get on and off board. Passengers pay to enter the system at the station entrance like in some rail systems (for example the Paris Metro or the London Underground). The coverage of the system is enhanced at end stations with a system of feeder routes with conventional buses to concentrate demand, in a fashion common to some rail systems (for example in the Caracas Metro). From the organizational point of view Transmilenio is a mixed institution. It is governed and coordinated by a public agency Transmilenio S.A. This agency coordinates the action of private operators that own and operate the buses and the fare collection system (www.transmilenio.gov.co).

The standard normative technical and organizational descriptions of Transmilenio do not mention many aspects that are crucial to its very existence. Three important aspects are revealed when Transmilenio is conceived of as a Large Technical System (Hughes, 1993; Summerton, 1992; Summerton, 1994; Coutard, 1999). First, Transmilenio is also a political system in at least two important respects. The CEO of Transmilenio is appointed by the elected mayor of the city and thus, Transmilenio is part of the political government of the city; and the system is designed to function as a public-private partnership with a set of rules that guarantee a delicate balance of power between the private operators and the public coordinating agency. Second, Transmilenio is the result of a planning process aimed at confronting the increasing inefficiencies of the "previous" collective system. The collective system had reached a level of stagnation that can be characterised as a *reverse salient*, that is, a critical situation whose causes cannot be isolated and solved by conventional rational processes (Hughes, 1993). The

concentrated efforts of a number of people produced a solution that generated a whole new system. Paraphrasing Thomas Hughes (1993) I can say that confronting the reverse salient led to radical innovation. And third, the development of the new large technological system was steered by engineers, urban planners and designers during the development phases. After the system began operation the initial innovators where replaced by another type of system builders with competencies in economics, finances and politics to steer the further stabilization and growth of the system. In other words the system builders and their competencies change as the system moves from the innovation to the maintenance and growth stage (Hughes, 1993, 1998).

The main emphasis of the Large Technological Systems theory is that all technical aspects of any system are political at the same time. They are intertwined in a seamless web (Hughes, 1986). How to account for that processes and what are its implications and consequences? To answer this question I will analyse two sides of the planning process: first, how innovators decided on the main technical aspects of the new system; and second, how this process implied a reconfiguration of the city of Bogotá. To do so, I will use some concepts of Actor Network Theory.

Figure 1: Transmilenio in Bogotá
Picture: Andrés Valderrama

THE "DE-SCRIPTION" OF LARGE TECHNOLOGICAL SYSTEMS

One of the problems that many analysts face when they attempt to account for processes of production of reality is the fixity of language. The majority of the concepts available are static. Additionally they refer to finished objects. There is an overemphasis in denoting what things are rather than accounting for the process that produced them: too many subjects, too few verbs. Actor-Network theorists have attempt to overcome this limitation by developing new concepts and even entire new sets of concepts that consciously avoid the limitations of positivist, modern, objectivist terminology (Latour, 1999). Madeleine Akrich (1992) made an early attempt of importing from the field of semiotics a number of concepts to enable this analytical task. The two fundamental Actor-Network Theory points of departure are first, that the social and the technical are

not distinguishable during the design process; and second, that the inside and the outside of any object, or in other words the boundary of the object is a consequence of the design process. Therefore, neither the social, nor the technical, nor the external, nor the internal aspects or features of any object are suitable to account for the process that produces that very object.

Akrich builds on the proposition that designers (and engineers and urban planners and politicians) producing new objects, in other words *innovators*, are applied sociologists (Callon 1987). Therefore, the task of designing an object necessarily implies a proposal for the setting in which that object will exist: a scenario. Akrich suggests that this process can be regarded as a process of *in-scription*. Put in her own words: "A large part of the work of innovators is that of "*inscribing*" this vision of (or predictions about) the world in the technical content of the new object" (Akrich 1992: 208). Analysing an object, thus, is a process of isolating the different inscriptions in an object: it is a *de-scription*. However, this process is not simple, because scripts are not stable. They change in time and through the interaction of innovators among themselves, with the imagined users first, and after with the real users, with constrains of all kinds (legal, physical, normative, cultural, technical), through the process of design, operation and maintenance. Therefore, at different points in time during the design, construction and operation processes of any technical object there will necessarily be a clash "between *the world inscribed in the object* and *the world described by its displacement*" (Akrich 1992: 209). Special actants in all these processes, the final users, will accept the object only to the extent they consent to the specific kind of world the object is proposing. This process Akrich regards as "to make a *pre-inscription*" (Akrich 1992: 215).

The language proposed by Akrich provides a tool to scrutinize the complex, contested and vexed process of design of any object. To illustrate the analytical capacity of this language she presents various examples of how objects designed in Europe by agencies of international cooperation, failed when operated in their final setting, which according to her accounts are various places in the less developed parts of Africa. Her point is that the world proposed by the designers was at odds with the world in which users actually lived. This set of examples, however, convey two suppositions that do not apply when the designed object is an urban transportation system: first, that objects are designed in one location and then transferred to the place of actual use; and second, that the new technologies are presented to the final users at one specific point in time, that is, that they suddenly propose a radically new set of relations. Although a good deal of the case studies of Actor-Network theorists among other constructivist approaches aim at overcoming this analytical limitation, many of the metaphors end up emphasizing the novelty of the new actor-world or system and its internal story. The laboratory and the socio-technical ensemble are cases in point (Jørgensen and Sørensen 2002).

I will carry out a *de-scription* of some aspects of Transmilenio in Bogotá to suggest ways to overcome these limitations. I will concentrate in four main features of Transmilenio: the design of the buses; the fact that both the buses and the stations are designed with high platform; the location of the stations in the median of the trunk roads; and the use of discriminated traffic. All these scripts are systemic: they are features of the system as a whole and they play a role in the relation of the components of the system. In contrast other aspects of certain components can be changed: for

instance, buses can be powered by diesel *or* natural gas engines. In other words, the fuel and the engine do not play a role in the way the bus interacts with the stations for instance.

Buses

The buses of Transmilenio are articulated with a maximum capacity of 160 passengers: 48 seated and 112 standing (Figure 2). They have four sets of doors in the left side of the vehicle to allow rapid boarding and off-boarding of passengers similar to rail systems. The layout and all dimensions are standardized.

Figure 2: Transmilenio articulated bus
Picture: Andrés Valderrama

There are three scripts in this vehicle design that are interesting for this analysis: first, few seats. Unlike in the collective system, in Transmilenio it is expected that passengers will not remain inside the vehicle for long periods of time, which depends on the velocity of the vehicle which in turn depends on having as few vehicles as possible in the road (450 new vehicles replaced 1140 conventional buses approximately). Second, four sets of doors on the left side of the vehicle. When the bus stops at a bus station the bus doors match sliding doors in the station. Passengers board or leave the vehicle in a very short time, which also improves the average velocity of the vehicle. This depends on the fact that the collection of the fare is separated from the vehicle, unlike in the collective system. And third, all red buses have the same exterior and interior design, unlike the vehicles of the collective system where it is hard find two that are similar.

The fact that the buses of Transmilenio are all standardized and with the features mentioned, reflects that the process of definition of its features was successful in this respect. However, it was a hard process. It began in 1998 when the small initial planning team succeeded in convincing 23 bus manufacturers around the world to bring a prototype to Bogotá for the double purpose of providing publicity for the project and for testing. The manufacturers accepted the invitation with the hope that the best would be awarded an order of 450 buses for the new system. All buses were tested by engineers of the Universidad de los Andes for mechanical performance, a key issue for a city built at 2.640 meters above the sea level, which implies very particular conditions

for machine operation (the most notable is an approximate 30% lower density of the air, and thus 30% less oxygen for combustion) (Huertas et. Al. 1999). The innovators soon discarded the small vehicles and concentrated on the larger ones, with the idea of reducing the maximum the number of vehicles required, which in turn was a response to the collective system that exhibited an excess of vehicles of more than 100%. The city of Bogotá had in 1998 more than 22.000 buses serving the city, where transport engineers calculated that between 8.000 and 10.000 were enough (Ardila-Gómez 2004).

High Platform

Figure 3: Transmilenio Bus Station
Picture: Andrés Valderrama

The buses and the bus stations are designed with a high platform of about 70 cm above the ground level (Figure 3). Of course all the vehicles and the stations comply with the standard in order to make the system work. This particular script was the result of the political process of design of Transmilenio. During the process, the planning team invited the current owners of bus companies to take part in the process. There were two strategic reasons: because the planners had a lack on knowledge with regard to how the collective system actually worked in organizational, political and economic terms; and it was also part of a strategy to break the resistance that the current "owners" of the business might pose. This led to their inclusion as sources of information and possible bidders for the contracts of the new system. Given that they would eventually run the risk of purchasing the buses and operating them, the planning team and the city authorities allowed the bus company owners to decide if they recommended high or low platform. They finally decided on a high platform. Once in place, the high platform also became a critical actant for the new system because it played a crucial role in making the new system physically incompatible with the collective system. In other words, in the event of political crisis in the relation of the city authorities and the private operators (divided since the year 2000 into those that became included in Transmilenio and those that remained in the collective system), the buses of the collective system would not use the dedicated lanes and the stations of Transmilenio; nor could the red articulated buses

of Transmilenio could operate as conventional buses picking up passengers at any point and using the door on the right side of the vehicle. (Ardila-Gómez 2004; Valderrama and Jørgensen 2008).

Bus Only Lanes

Figure 4: picture of the Avenida Caracas as it was designed and functioned from 1991 to 1999
Picture: Courtesy of Transmilenio S.A.

Since 1988 the transport authorities and experts in Bogotá had been trying to solve the problems associated to the seemingly disorganized and fragmented collective system in Bogotá. Many would not regard it as a system since both the property and the responsibility where too fragmented. The first attempt to re-organize the whole system was watered down to a proposal of discriminating traffic in the Avenida Caracas, the backbone of the transport corridors of the city. Following experiences in Brazil and with the participation of Brazilian consultants, the city authorities redesigned the avenue providing for a corridor in each direction of two bus only lanes (Figure 4). This arrangement began operation in 1991. Transit was only permitted to large conventional buses with a capacity of 80 passengers seated and a small corridor in the middle of the vehicle. The urban design of the corridor was poor, which attracted furious criticism from citizens and urban experts alike. However, the technical performance of the corridor was remarkable. Measures of capacity showed that this arrangement could make the bus system as efficient as some rail system with a peak of 24.000 passengers per hour per direction. When the city authorities, the planning team and Major Enrique Peñalosa, designed the bus rapid transit project between 1998 and 2000, this particular script played on their side both providing a technical background for the new design and an existing example of the benefits of discriminating traffic (Adila-Gómez 2004).

Bus Stations

The location of stations in the centre of the median is one of the scripts in which Transmilenio really stands alone. All the other reference projects, including the famous Curitiba in Brazil and the former Avenida Caracas in Bogotá, had buses circulating in the central lane, but the bus stops were on the right side of the vehicle, in the pedestrian separator of the bus lanes and the mixed traffic lanes. This script plays a crucial role because it allows the system to have a particular boundary. The passenger pays when entering the station and then it can remain inside for as long as he/she wants to, as in the

Paris Metro or the London Underground and unlike many other transport systems where there is a limit for the time one can remain inside the system. Once the passenger has paid, he/she can board and on-board any bus or change direction at bus stations, and like many train stations, it allows for free transfers. The boundary, is also enacted by a sophisticated (some claim exaggerated) computerized system with electronic cards, turnstiles and paying booths at the entrance of stations. This particular script also breaks clearly with the tradition of the city of having the collection of the fare inside the vehicle and the driver as responsible for this task.

Scripts: conclusion

The design of Transmilenio reveals three key aspects of the process: first, that the process of inscription of the new system was performed in the location where the new system would operate and the whole process was influenced by readings of the current situation, especially analyses of the problems of the collective system and proposals of how to produce a new scenario where these defects would be left out by design. This is why I have emphasized in the description of the scripts of Transmilenio that they were different from the scripts of the collective system. The innovators of Transmilenio consciously addressed many of the features of the new system to avoid what they considered to be the distortions of the collective system (Ardila-Gómez 2004).

The second key aspect is that the process is contingent on the interaction among different actors including planners, politicians and current bus operators. I must clarify that the planners group is quite heterogeneous as it includes: local planners in charge of the design of Transmilenio; local consultant firms and academic experts; and international consultant firms like Steer Davies and Gleave; MacKinsey and Logitrans. Additionally, it is also revealed that many existing non human actors or previous scripts, like the “old” solo-bus Avenida Caracas and the bus stops in the median, support many of the inscription processes of the new design. In this sense, all new scripts are networked entities that emerge from a process of juxtaposition and translation (Callon, 1987) of many other actors located physically inside and outside the city of Bogotá.

And third, that all these scripts were aligned to enact a clear boundary between the new system and the existing collective system in order to make the innovation process irreversible (Callon 1991). This is the most notable contribution of Actor-Network Theory to Large Technical Systems Theory: systems are made to exist, they are produced. The process that configures the system necessarily has to define a boundary. And this boundary is the result of distributing agency, causes and responsibility to a number of actants in the new system including operators, drivers, city authorities, high platforms, sliding doors, discriminated traffic lanes and so on (Akrich 1992; Law 2002; Valderrama and Jørgensen 2008). And this boundary is the result of the action of those features inside the system that were made to oppose those features that ended up outside the system during the design and planning process. In other words, the design of the new system was performed in a world where other existing technologies or actor-networks or large technical systems were already functioning. To characterize the interactions of technologies or actor-networks of transport and how they are constitutive of the city of Bogotá I now turn to the concept of arenas of development.

ARENAS OF DEVELOPMENT: THE CONCEPT

Actor-Network theorists have attempted to analyse the process of innovation following the workings of different actors. Callon (1986, 1987) followed the efforts of a group of engineers within the French state prestigious giant company Electricité de France to design a new transport system for France based on electric vehicles to replace the private car system entirely at the beginning of the 1970s. Callon describes the different strategies pursued by the engineers to interest and *displace* other existing human and non-human actors like battery accumulators, car manufactures, city authorities in France, drivers and so on. These engineers attempted to become spokes persons for these entities and thus become an obligatory passage point and therefore make the networked entity of the electric vehicle function. The whole process Callon denominates as *translation*.

Callon (1986, 1987) explains that this particular electric vehicle project failed because a number of actors resisted to be incorporated into the network: the accumulators did not become economical; Renault continued to be a combustion engine car manufactured and so on. Because he focuses on the workings of one actor, the analysis does not account for what other actors did to preserve the other technologies in place: the combustion engine cars; the trains; the buses; the rail systems; etc. In a similar fashion Latour (1997) explains the failure of another group of engineers in Paris to develop the urban transport system Aramis between 1972 and 1989, in the lack of effort (or love as he puts it) of the central actors to make the whole network cohere and hold in place. In both cases, the focus on following a specific set of central actors obscures the workings of the other existing or even projected technologies.

To overcome these limitations Jørgensen and Sørensen (2002) propose the concept of arenas of development which is a cognitive space for research that aims at improving our analytical tools to account for the dissimilar processes that produce conditions for innovation. The concept provides a basis for analysts to shift the focus from the new entity –the actor-network or the new large technical system– to the set of interactions that makes possible the emergence of the new entity and its relation with the existing ones throughout its becoming. It differs from other concepts like a socio-technical landscape which convey a notion of natural order; or a technological regime (Geels and Schot 2007) which assigns an internal natural logic to a context of development. An arena of development is populated by many actor-networks or large technical systems that compete, interact, interfere or complement each other. The arena is composed of: a number or elements such as actors, artefacts and standards; a variety of locations for actions, knowledge and visions; and a set of translations that shape the stabilizations and destabilizations in the set of relations of the arena (Jørgensen and Sørensen 2002: 198).

In this section I will argue that Transmilenio was designed to produce a major change in the arena of development of urban transport in Bogotá. The project was intended not only to solve a technical problem of mobility, but to reconfigure a whole set of relations including power relations, spatial and distance relations and identity relations within the city of Bogotá and at national and international levels. The innovators in this process not only struggled with the existing technical systems of collective transport and the private cars, but also with the non-built, but much discussed, project for the Metro of

Bogotá. This engagement with local technologies in use was also an engagement with the international networks that support these technologies (Edgerton 2006). The struggle also incorporated a discussion of different chronologies and images of the old and the new (Bender 2006).

The arena of development of transport in Bogotá

Ardila-Gómez (2004) has elaborated a very detailed history of the planning and decision making process that led to the design and construction of Transmilenio in Bogotá. In this section I want to refer the elements that position the new system within the context of the existing technologies in the city of Bogotá. The objective is to trace the interdependencies among technologies, that otherwise are normally conceived of as independent modes of transport (Lay 2005). To do so I will concentrate on three movements, each one related to the other three major technologies in the arena of technology of transport in Bogotá: the collective system, the non-built Metro and the private car.

First movement: the collective transport becomes dominant

By the beginning of the 1980s the arena of development of transport in Bogotá was composed of a collective public transport system; a public car system (taxis); and a private car system. The dominant mode of public transport was the collective system. This was a particular system organized around transport companies, which had the responsibility of managing routes for public transport in the city. This responsibility was delegated by the city authorities via the Secretariat of Traffic and Transport. The transport companies affiliated buses: this means that they did not necessarily own the buses, but allowed bus owners to serve their routes in exchange for a lump sum for affiliation and a monthly fee. Particular individuals owned the buses. They were normally small investors and on average there were more than one owner per bus. The bus driver was occasionally a hired person, but more often than not one of the owners of the bus. In practical terms this meant that the driver performed all the work: cleaning and maintenance of the bus, driving and collecting the fee from passengers. At the end of each day the driver would give the owner a portion of the income. The owner would in turn pay the monthly fee to the transport company. In legal terms all the responsibility of operation was assigned to the bus driver. This meant that transport bus companies received money without being responsible for any service or failure in the service. It also meant that drivers competed in the street to pick up passengers which resulted in competition and aggressive behaviour with very high rates of accidents and mortality. This particular phenomenon was denominated “la guerra del centavo”, the cent war, and came to be regarded as the core of the problem (Acevedo y Barrera 1978).

This particular organization of the urban transport sector began in the 1920s when the city authorities allowed private buses to serve the new settlements of the city which could not be served by the existing tram system. The system grew rapidly due to the flexibility of the then new technology; the fact that private operators assumed the risks; and the inflexibility of the tram. The inflexibility of the tram was due to the technology used; and the fact that it was owned and operated by the city and was thus subject to political struggles among competing parties. Between 1930 and 1952 the new bus

system grew, while the tram stagnated. The political and economic support for the tram diminished and finally the tram was dismantled (Castañeda 1995). During the second half of the 20th century all efforts by the city to regulate and structure the collective transport failed including: the purchase and operation of city owned buses (both internal combustion and electric powered trolley buses); strengthening the regulation; and various attempts of reorganization. By 1998 68 bus companies affiliated around 22.000 buses owned by more than 25.000 persons. The fact that the property was distributed among so many people, made the system quite stable. In other words any effort to change the whole system could not be undertaken by one company alone. (Ardila-Gómez 2004).

Second movement: the various projects of the Metro of Bogotá

The Metro of Bogotá became a key player in the transformation of the arena of development of transport in Bogotá since 1982, albeit the fact that it was never constructed. Based on studies carried out during the 1970s, the national government made the decision to commit the nation to support any metro development in any city in Colombia by way of serving as the guarantor for loans taken in the international financial market. Medellín, the second city of the country, took the offer and began designing its own elevated metro. A number of transport experts in Bogotá opposed the project for the city on the grounds that it was too expensive and other solutions with buses were possible. In 1988 the president of Colombia, Virgilio Barco, a Civil Engineer from the MIT proposed to develop another Metro for Bogotá using the old train corridors. The proposal evolved to the point where the Italian consortium Intermetro won the rights to design and construct the system. A growing number of experts with increasing influence in the city administration managed to delay this project specially criticizing the forecasts for passenger demands, because the old rail corridors basically did not have much demand as they traversed the city mainly across non residential areas.

In 1989 the construction of the metro of Medellín was halted due to escalating costs. As a reaction to the critical situation in Medellín, but also considering the costs of a possible urban train system for Bogotá, the National Congress approved the so-called Metro Law at the end of 1989. The new legislation allowed local governments to raise taxes by 20% to cover the costs of the infrastructure development. This law also established that local governments should cover at least 80% of the total investment costs, and that the nation would cover at most 20%. The law demanded that the fare income of the new systems covered operation costs and depreciation of the equipment. This law made it ever more difficult for the city of Bogotá to aspire to develop a metro system. Andrés Pastrana, then Mayor of Bogotá, followed the advice of the local transport experts at the moment focusing the efforts of the administration in the development of a solo bus system, instead of a Metro. During 1995 the Japanese government gave as a present to the city of Bogotá a comprehensive study of the transport situation of the city and made a recommendation for future development. The study basically proposed the development of a three level city with elevated highways for private transport, a surface bus rapid transit system for passengers and an underground metro. In 1997 Enrique Peñalosa ran for major and won the elections with the promise of constructing a metro for the city of Bogotá. During his tenure he

established a working group to develop the project and signed an agreement with the national government to partially fund a package for the development of a new bus *and* a metro system for Bogotá. During his administration Peñalosa negotiated part of the resources to build Transmilenio and strategically withdrew the attention on the metro eventually dismantling the planning team in charge of the project.

Third movement: containing the public space for private cars

Like many other cities in the world Bogotá did not develop a significant car dependency as the number of vehicles never reached the proportions of the US or Europe. However the car became a key player in the discriminated character of the city. In the first place the majority of car owners lived to the north in the wealthier neighbourhoods, where the road infrastructure was better. But furthermore, during the 1970s and 1980s the car began using more and more areas of the public space that were designed for other purposes. Therefore it became common for drivers to park their vehicles on the sidewalk, green areas and even parks. Congestion rapidly became a problem in a city that never spread out too much and became quite dense. In 1982 the city administration undertook the first major project to contain the public space used by cars. On Sundays 120 kilometres of main roads in the city were closed for traffic, allowing for pedestrians, cyclists, and people on skates and so on to enjoy the city for sport and recreation purposes.

In 1989 the city administration decided not to build a metro, but the solo bus system on the Avenida Caracas. Although the idea was to re-organize in its entirety the whole organizational and technical system along the corridor, the idea was watered down to an infrastructure that discriminated bus traffic from the rest. The space allowed for private cars was thus reduced from three to two lanes, albeit the interference with buses was removed. During the 1990s the congestion in the city reached unexpected levels with the traffic collapsing entirely in at least two occasions. During his first year in office Mayor Peñalosa enforced a car restriction program. In weekdays 40% of the private cars were not allowed to run during peak hours (7-9 am; 5-7 pm). With time the timeframe has increased. Peñalosa enforced another tough measure to remove cars parking on the sidewalk and completely forbade this practice at least in the main corridors of the city. The containment of congestion became an integral part of prioritizing public transport developments.

Arenas of development: conclusion

The movements described in this section are not mere descriptions of the other actor-networks that populate the arena. It is overall an attempt to trace the ways in which each system configures the arena and acts and re-acts to the other systems. The first movement traces schematically the ways in which the collective system became the dominant mode of public transport in the city, thus framing the type of technical problems that the planners of Transmilenio addressed in the design of the new system. The second movement relates the workings of the particular actor-network of the metro of Bogotá. An actant of variable geometries that was nevertheless quite effective in providing a scenario of development that triggered energetic responses from transport experts in Bogotá. During the 1990s it also became instrumental in mobilizing resources

from the nation to the city especially for the construction of the infrastructure of Transmilenio. And finally the arena of transport in Bogotá has been also populated by an ever increasing number of private vehicles that create problems of congestion on roads and other public spaces. The regulations designed to contain the private car are also part of a discourse of improvement of the public transport system and thus are linked to the development of Transmilenio.

CONCLUSION

The analysis of the arena of development of transport in Bogotá shades new light on the agency distributed to the different scripts of Transmilenio. They are not just technical features that respond to the previous organization of the arena. They also become actors in the new order. The lanes, the stations, the high platform and the vehicles are conceived to enact a boundary to separate the new from the existing. They also perform to the stability of the system and disciplining future Mayors and city authorities (Valderrama and Jørgensen 2008). They play a role in the physical reorganization of the city and thus in the lived experience of citizens, thus re-defining space and time in Bogotá. And finally Transmilenio also co-produces de identity of the city and its citizens.

Throughout the text I have referred to the collective system as the "previous" or the "old" system. I have used those words because many analysts and Peñalosa himself uses them. The choice is not accidental or naïve. The stories told through these analyses participate of a narrative to construct the notion of Transmilenio as the future of Bogotá and the collective system as its past. It is a conscious enactment of a trajectory of development aimed at strengthening the further growth and extension of the system. This paper plays its role in further producing both the system and Bogotá as a networked entities that also exist in academic texts in different locations around the world.

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Accessibility in urban transportation systems (forthcoming)

Through sensorial inspection, an analyst of Transmilenio can read some features that reveal the system as an inclusive technology that guarantees access to diverse handicapped groups: there are ramps and elevators for people using wheelchairs; there are dynamic visual displays in the buses for those with hearing limitations; and there are voice announcements for the blind. However, these elements are not in place because the designers and operators of Transmilenio willingly included local concerned groups of people with disability as valid sources of knowledge. Local concerned groups and individuals have achieved influence in the design of Transmilenio through various means, including lobbying, the development of standards and legal suits. In turn, Transmilenio has implemented accessibility, because it is a *mobilizable* actor: the sociotechnical configuration of the system allows concerned groups the possibility to actually have influence. In this article, I present and analyse the processes that have made possible the influence of users in the modification and introduction of scripts in the system that make possible a certain distribution of agency that effectively allows accessibility in certain parts of the system. I also discuss how and why Transmilenio is the first system in the arena of development for transport in Bogotá where such influence is at all possible.

This article is part of a collective effort to publish a special issue in the journal, *Science, Technology and Human Values* on *Disability, Mobility and STS*. The leaders of this effort are Vasilis Galis from the University of Linköping in Sweden and my self. The current proposal includes contributions from Sebastián Ureta on access to Transantiago in Chile; Greg Nijs and Amélie Daems on mobility of the elderly in Belgium; and Vasilis Galis on the design of the Athens' Metro.

Accessibility in urban transportation systems: an STS approach

Andrés Valderrama
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This article is part of a collective effort to publish a special issue in the journal, *Science, Technology and Human Values* on *Disability, Mobility and STS*. The leaders of this effort are Professor Vasilis Galis from the University of Linköping in Sweden and my self. The current proposal includes contributions from Sebastián Ureta on access to Transantiago in Chile; Greg Nijs and Amélie Daems on mobility of the elderly in Belgim; and Vasilis Galis on the design of the Athens' Metro.

Abstract

Through sensorial inspection in 2010, an analyst of Transmilenio can read some features that reveal the system as an inclusive technology, which guarantees access to diverse handicapped groups. There are ramps and elevators for people using wheelchairs; there are dynamic visual displays in the buses for those with hearing limitations; and there are voice announcements for the blind. However, these elements are not in place because the designers and operators of Transmilenio voluntarily included local concerned groups representing people with disabilities as valid sources of knowledge. Local concerned groups and individuals achieved influence on the design of Transmilenio through various means, including lobbying, the development of standards, and legal action. Transmilenio then implemented accessibility, because it is a *mobilizable* actor: the sociotechnical configuration of the system actually allows concerned groups the possibility of influence. In this article, I present and analyse the processes that have made it possible for users to influence the modification of the system and introducing scripts that enable a distribution of agency that effectively allows accessibility to certain parts of the system. I also discuss how and why Transmilenio is the first system in the arena of development for transport in Bogotá where such influence is at all possible.

Introduction

The urban transportation system Transmilenio began operation in Bogotá, Colombia, in 2000. It is a bus system that incorporates many features formerly belonging only to rail systems: buses are large, accommodating up to 160 passengers; buses stop at stations in the median of the road rather than bus stops at the curb; buses have four sets of wide doors on the left side of the vehicle, which open and close simultaneously; the platform of the bus and the platform of the station are at the same level; and the fare is collected at the entrance of the station, not in the bus (Wright and Hook, 2007). All these arrangements, plus a special interior design of the bus and the access to the stations, allow for better accessibility, especially for people with diverse disabilities (Figure 1). The new system introduced another aspect to city life in Bogotá that did not exist before: regularity (Ardila-Gómez 2004; Hidalgo and Hermann, 2004; Shane, 2006). Services, routes and buses comply with a regulated schedule, which makes mobility for blind people a lot easier.

In spite of all the advances conceived and implemented by that the designers and operators of Transmilenio, there are still many shortcomings. The features described above apply only to the trunk lines of the whole system. The feeder lines leading to the edges of the city do not have these advantages of accessibility. As a consequence, the system discriminates – people living close to the trunk lines have better access than those who do not. "Go live close to the trunk lines!" (Redacción DISSNET, 2005) was the aggressive response of former Mayor of Bogotá, Enrique Peñalosa, when individuals with disabilities, associations and journalists started to complain about the lack of accessibility to the feeder lines.

Figure 1. Pictures displayed in the official website of Transmilenio to show that the system guarantees accessibility to persons with disability. Retrieved from http://www.transmilenio.gov.co/WebSite/Contenido.aspx?ID=PoblacionEnSituacionDeDiscapacidad 23 February 2010.

The advances and the shortcomings described above reveal not only the contingent and multiple character of the design process, and science's co-production with the social order, that have been proved in STS studies for decades (Jasanoff, 2004), but they also reveal the difference with regard to what knowledge is considered legitimate and what is dismissed as irrelevant, when designing and improving a new transportation system. This paper addresses this issue with special attention to the role of persons with disability and organizations representing them, the resources they mobilized, and the response they received from the system builders of Transmilenio. The main point is to prove that disabled people had to make a great effort in order to be taken into account. There is no room for ontological symmetries here: the colonial structures of normality – i.e. naturalized differences of superiority and inferiority – operate here as they do in scenarios where race, gender and nationality are at work (Maldonado, 2007; Moser 2000).

The analysis is organized in the following sections: First, I present the theoretical framework, introducing the concepts of emergent concerned groups and arenas of development; second, I argue that with Transmilenio, accessibility first materialized in

some basic and unconnected material scripts in the arena of development for transport in Bogotá; third, I present the case of Daniel Bermúdez, and how he was successful in suing Transmilenio for not guaranteeing accessibility; and finally, I draw some conclusions and I outline some future lines of research.

Emergence of Concerned Groups in an Arena of Development

For decades Science and Technology Studies' scholars have been concerned with the limitations of their analytical tools in relation to accounting for those who do not have voice in technology and knowledge development (Winner, 1993). To fill this lack, Michel Callon and Vololona Rabeharisoa (2008) defined the concept of emergence of concerned groups by studying the evolution and consolidation of the *Association française contre les myopathies* (AFM). They use this concept to characterize the process by which a group of persons traditionally considered lay people (such as patients, patients' relatives, social activists, etc.) become increasingly empowered to influence a whole scientific field. They become empowered, because they consolidate a working network that starts accumulating knowledge about their own matter of concern (Latour, 2004) – in their case, muscular dystrophy. With time and a lot of work and interaction with politicians, doctors and public administrators, the association became strong enough to influence research agendas on muscular dystrophy; that is, they slowly changed from a position of passive exclusion to a role of active inclusion. In the process, their identities changed (Callon and Rabeharisoa, 2008: 235). The story of AFM is the story of a community of knowledge or a hybrid research collective – to use Callon and Rabeharisoa's conceptual choice (2008: 238) – that successfully developed into a strong actor in France's research community on muscular dystrophy. The collectives and individuals I refer to in my analysis are struggling on the path to knowledge and power accumulation in order to win accessibility to the built environment in Bogotá.

I have argued elsewhere that it is appropriate to conceptualize a city as an arena of development of transport technologies (Valderrama and Jørgensen, 2008; Valderrama, 2009; Valderrama, forthcoming 2010). An arena of development is basically the interaction of many actor networks. In the case of transport in cities like contemporary Bogotá, there are a number of sociotechnical systems that populate the arena. These systems interact in diverse ways, sometimes competing, other times cooperating, or in combinations of competition and cooperation. The city, with its particular space-time, is the outcome of this interaction. The concept is useful, because the arena is also populated by individuals, passengers, regular users, non-users, mediators, end-users, lay users, implicated actors and a whole set of entities that are increasingly brought into analyses of design and knowledge production (Oudshoorn and Pinch, 2005). However, the arena of development concept is also flat: it makes no assumption about the nature of the entities and observes them through their activity. Therefore, it can also account for the dynamics that produce inclusion and exclusion as a result of interaction (Jørgensen and Sørensen, 2002).

The emergent concerned groups of people with disability, which include individuals and associations in Bogotá and Colombia, also populate the arena of development. Since 1998, Bogotá has undergone a mayor transformation, which has been positive in many

respects for the accessibility of the population at large to services, especially transport. However, the process has been tortuous and vexed, in relation to the participation and inclusion of people with disability. In the next section, I argue that the initial impulse for this improvement did not come through participation, but through top-down design activities. The result, however, produced an impulse in the concerned groups to gain momentum and influence further developments.

Accesibility comes to town

The design and construction of Transmilenio's first phase, between 1998 and 2000, introduced in Bogotá a technological and material configuration that allowed access to public transport to groups of people with disability for the first time in Bogotá's history. It is worth mentioning the physical elements that enabled this accessibility by contrasting the new system with the previous bus system (if it can be called a system at all!). The arena of development of public transport in Bogotá had been completely colonized by the *transporte público colectivo* TPC, which was based on a semi-competitive model in which bus companies managed routes with a high degree of superposition: many routes used the same corridors or parts of corridors (Valderrama, 2009). This arrangement produced competition among busdrivers for passengers, and thus a hectic driving behaviour. The vehicles complied precariously with an also precarious standard. The majority of the buses where composed of artisan and semi-industrial bodies mounted over truck chassis; they had a very narrow door, which segregated persons with disability (Figure 2). The organization of the TPC did not allow for regularity. There were no schedules, but frequency was high, so passengers' waiting times at the curb were short. However, blind people could not wave to their buses without help.

Figure 2: Picture of a typical TPC bus in Bogotá, Colombia. Picture taken from Rickert (2008)

The developers of Transmilenio introduced various material scripts that made accessibility possible: first, a fixed infrastructure with bus stations that were located in the median of the roads. Second, the system's buses were scheduled by a central public

agency, Transmilenio S.A., with technical capacity to plan and control operations so they could establish regularity. Third, all stations became manned with personnel from Transmilenio S.A. and from the police to support and aid passengers to find their way around the system (which can also be a cognitive challenge even for the most technically skilled user (Valderrama, forthcoming)). Fourth, access to the stations was provided with ramps to allow persons in a wheelchair to reach the station from the sidewalk. Fifth, the stations and the buses were designed with platforms at the same height, which enabled access for persons with disability (Figure 3).

Figure 3. Picture showing the ramp to the station and the levelled access between the station and the bus. Picture taken from Rickert (2008)

The designers of Transmilenio interacted with diverse social groups, companies, interest groups, politicians and potential users during the process of design and construction of the system (Ardila-Gómez, 2004). However, during this process, the designers granted access to the core designing team and network only to a few social groups, companies and politicians, and carefully fenced out many actors that had the potential to influence the design (Valderrama, forthcoming 2010). The designers of Transmilenio did not approach associations of people with disability nor were such individuals invited to give their points of view. Those who approached the designing team on their own initiative, like Mauricio Gaitán, a blind social activist who advocates universal access, were heard, but their suggestions were not taken into account.

The material scripts mentioned above were included mainly because the model for Transmilenio possessed them. In fact, the trunk lines of the Rede Integrada de Transporte RIT (Integrated Transport Network) in Curitiba, Brazil, exhibited the material scripts (ramps, platforms, adapted turnstiles, sliding doors) that were also implemented in Bogotá. It was the international referent that counted for the designers, not the local contribution of individuals and groups with disabilities.

Tutela

On 28 February 2001, Colombian citizen Mr. Daniel Arturo Bermúdez Urrego sued Transmilenio S.A. for not guaranteeing him accessibility to the transportation system. Bermúdez used the legal instrument *tutela*, which was established by the country's constitution of 1991. This legal instrument allowed individuals to sue other individuals, organizations or the state itself, if their basic rights were violated. Mr. Bermúdez argued that Transmilenio S.A. had implemented only partial accessibility to people like him with disability. The main reason was that he lived 15 blocks away from the trunk lines, where access was guaranteed. A feeder route passed very close to his home but had no devices to facilitate access for persons in wheelchairs like him. His argumentation was supported by various laws, decrees and technical norms developed during the 1990s, which mandated the provision of accessibility for people with disability to all services, including transport (Cepeda Espinosa, 2002: 2).

Transmilenio S.A. argued that the transportation system was composed of two different technologies: the trunk lines with new buses, new stations and all the devices to facilitate access; and the feeder lines, which basically complied with the requirements of the Ministry of Transport for companies that provide transport service in the traditional TPC mode described above (see page 4). Transmilenio S.A. also argued that compliance with the legislation was in process, but that the costs of full accessibility threatened the economic sustainability of the system as a whole, and that increased costs would imply higher prices for all passengers (Cepeda Espinosa, 2002: 4). The judge ruled in favour of Transmilenio S.A. on 15 March 2001. The basic argument was that transportation companies should proceed to develop full accessibility, but through a technically and economically sound process, and that such actions should be exempted from the peremptoriness of legal actions like the *tutela* (Cepeda Espinosa, 2002: 5).

Mr. Bermúdez did not accept the decision and resubmitted his *tutela* for consideration at the Constitutional Court. The court magistrates considered the whole case and ruled in favour of Mr. Bermúdez on 1 August 2002. The court *problematized* (Callon, 1986) the situation in the following juridical terms:

> Does the company in charge of the management, organization and planning of the transport service in a city ignore the right to equality, liberty of locomotion and protection of a special person who lives in a marginal area, and who uses a wheelchair because of disability, and who does not have access to transport because of his condition? (Cepeda Espinosa, 2002, translated from Spanish by the author).

Magistrate Manuel José Cepeda Espinosa developed an extensive argumentation, bringing in examples of diverse sectors to demonstrate that despite the fact that legislation and technical norms are still in the making, the public company Transmilenio S.A. should guarantee access to the feeder lines to Mr. Bermúdez. This should be accomplished through the development of an access plan in a period no longer than two years. Transmilenio S.A. was also obliged to report progress every three months to the *Asociación Colombiana para el Desarrollo de las Personas con Discapacidad*

ASCOPAR (Colombian Association for the Development of Persons with Disability) (Cepeda Espinosa, 2002: 33).

This was the first time in Colombia's history that a transport company was forced to provide access to persons with disability in wheelchairs. Why was Transmilenio S.A. susceptible to mobilization, while many other companies, which had been operating for years, did not (and still do not) comply? In the next section, I present Transmilenio as a *mobilizable* actor.

Transmilenio becomes *mobilizable*

I have explained elsewhere why and how the *transporte público colectivo* TPC colonized the arena of development for transport in Bogotá (Valderrama, 2009). This system or mode of transport was characterized by unclear distribution of legal responsibilities among the city, the company owners, the bus owners and the drivers. Castañeda's (1995) account of the history of the TPC states that throughout the 20th century it became legally over-regulated, while its very structure made it physically and economically under-regulated. For instance, in case of an accident or a traffic infraction, it was the driver who had civil and penal responsibility, while bus and company owners did not.

The designers of the Transmilenio conceived many of the features of this transportation system, including material scripts to specifically address the many problems that the TPC presented (Valderrama, 2009; Valderrama forthcoming 2010). One such problem was the unclear distribution of legal, operational and economic responsibilities among the main actors that compose the system. This is the motivation behind constituting Transmilenio S.A. as a managing and operational agency with full responsibility for the system as a whole. In fact, the City Council established Transmilenio through agreement number 4 of 1999, which made this institution responsible for "planning, managing and controlling the system". The nature of the organization of the system, with Transmilenio S.A. as the coordinating agency and private operators as owners of the bus fleet, made it a public-private partnership which acted as a managing and executing company, not a regulating agency. Accordingly, and this was part of the argumentation of magistrate Cepeda Espinosa, Transmilenio S.A. cannot avoid the responsibility for providing access to Mr. Bermúdez as the traditional companies of the TPC had done until then.

Since 2004, Transmilenio S.A. has installed a number of elevators in the feeder route buses to guarantee access for people in wheelchairs (see figure 4). However, not all the feeder line buses have this type of device to facilitate access. As in many other transportation systems of the world, there is still a long way to go on the road to universal access, but what the story of Transmilenio S.A. and Mr. Bermúdez reveals is that certain performances in an arena of development become possible only when new actors are constituted in such a way that users can in fact make them *mobilizable*. In our case, the particular constitution of Transmilenio, the existence of the *tutela* as a legal recourse in Colombia, and the knowledge accumulated by Mr. Bermúdez and ASCOPAR made possible a modification of the design of Transmilenio to provide for improved accessibility. This particular episode has also supported further improvements

for other groups of people with disability, such as the deaf (dynamic displays inside the buses) and the blind (voice announcements). The whole set of activities has given the concerned group of people with disability further access.

Figure 4: Elevator in a feeder bus. Presentación General Transmilenio (Power Point). December 2008.

Conclusions

As in the case of the design of the metro in Athens (Galis, 2006), the case of Transmilenio in Bogotá reveals that the incorporation of devices and scripts to provide for accessibility of persons with disability is neither a rational nor a rosy participatory process. It is a highly contingent process, where designers and members of emergent concerned groups interact in antagonistic fashion. In this case, designers brought in economic estimates and financial figures to support their view that increased accessibility threatened the sustainability of the project itself; emergent concerned groups, on the other hand, had to elaborate a discourse on values, rights and social improvements to counteract the weight of economics. This struggle usually happens at various sites that constitute the arena of development. In this paper ,I have presented the details and results of the struggle after it was successfully taken into the higher constitutional courts, where technologies also revealed their juridical nature and were discussed in those terms. In short, the concerned groups of people with disabilities struggled to translate disability issues into material devices that enabled accessibility. They succeeded by enrolling the constitutional courts in the process, and also because Transmilenio S.A. was constituted in such a way that mobilization was possible in an arena of development where previously that possibility had not existed at all.

If disability is viewed as a network property instead of a situation affecting individuals, perhaps recent developments can provide a basis for better understanding how

responsibilities are distributed, and therefore clarify disability as a problem for people *and* the built environment. In Ingunn Moser's words:

> the actor-network discourse abandons the individualised human subject as the only possible starting point, and asks how this kind of agency and subjectivity is rendered possible. Actor-network discourse places ability and disability on an equal footing, as the result of how specific sets of relations of which we are part are arranged and organised. This is a landscape in which the norm no longer occupies a privileged position or has normative power (Moser, 2000: 236).

However, the case of Transmilenio and Mr. Bermúdez shows that shifting the view from the individual to the network does not alleviate the struggle. Achieving a habitable built environment is a battle.

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Sandra Cortés, INCI, Bogotá, 11 December 2009
Humberto Eslava, Ascopar, Bogotá, 27 Agosto 2009
Mauricio Gaitán, Bogotá, 27 August 2009
German Lleras, Steer Davies and Gleeve, Bogotá, 10 February 2009
Gustavo Martínez, Instituto de Desarrollo Urbano, Bogotá, 21 February 2010

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Shane, D.G. (2006) “Urbanism: A bus system transforms Bogotá’s prospects’”, *Architecture*, 95: 54.

Valderrama A. (2009) “How do we co-produce urban transport systems and the city? The case of Transmilenio and Bogota” in Bender, Thomas and Farias, Ignacio (Eds.) Urban Assemblages: How Actor-Network Theory Changes Urban Studies, Routledge

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The cases of Transmilenio in Bogotá and Metro in Copenhagen”, Ph.D Dissertation, Department of Management Engineering, Technical University of Denmark.

Valderrama, A. (forthcoming) “The Map of Transmilenio”

Valderrama A. and Jørgensen U. (2008) “Urban transportations systems in Bogotá and Copenhagen: An approach from STS”, in *Journal of Built Environment* 34 (2).

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The Map of Transmilenio (forthcoming a)

In this article, I deal with the design of the map of Transmilenio. This inscription is of special interest, because it is one of the key scripts for the functioning of the system; it aims to represent the whole system so that passengers to navigate it. Three actors met and struggled to influence the character, principles and final outline of this document: the Transmilenio operations experts, who want to maximize the performance of the system as a whole; the communications experts of Transmilenio and their supporting consulting staff at Steer Davies and Gleeve in London, who have particular views on the users based on a whole body of knowledge of signage; and the users themselves, who participate in various ways, including a webpage forum. The analysis in this document reveals how users actually struggle to influence the design of the whole system, and how the system builders of Transmilenio deal with these efforts.

This article is also intended for publications such as *Science, Technology and Human Values* or *Social Studies of Science*. I am currently collaborating with Katrina Boulding from the University of California at San Diego, who is developing an analysis of dynamic on-line maps and the development of the San Diego fire of 2003. We intend to send the articles at the same time, since they both deal with dynamic representations, knowledge, navigability and organized action.

The Map of Transmilenio: Representation and Expertise in a Sociotechnical System

Andrés Felipe Valderrama Pineda
afvp@man.dtu.dk
Draft 26 March 2010

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Introduction

In this paper, I address the question of how actors produce a map so that users can navigate in a large sociotechnical system. This subject is part of a larger project that investigates what designers do to conceive, develop, build and operate large sociotechnical systems. The case study is Transmilenio in Bogotá (Valderrama, 2009; Valderrama and Jørgensen 2008; Valderrama and Beltrán, 2007; Valderrama, forthcoming 2010).

I concentrate on the role of experts, because I found during my data collection that there were conflicting views among different experts on what a map should be, how to design it, and what information should be delivered to the user, understood as the passenger. However, experts' discussions also entailed defining the range of users for the map itself, since operation engineers and planners also visualized the map as a working tool. Passengers and other users also participated actively in the design of the new map through three activities: a test exhibition of possible maps setup by communication experts; regular surveys to assess the quality of the service provided by Transmilenio; and the various web pages (like www.skyscrapercity.com) and web log of surumbo.com, where users delivered countless suggestions for the improvement of the navigating tools and the signage of the whole system. Therefore, the map of Transmilenio is the result of interaction among operations experts, communications experts and passengers, some of which achieve contributory expertise (Collins and Evans, 2002).

Because the map of Transmilenio is the first transport map ever to be used in Bogotá, its iconic character is also relevant. The analysis of the elements that come into this organizing script (Akrich, 1992) or inscription and those that are left out is also important in trying to make sense of the one single inscription in use today that represents Transmilenio and the city of Bogotá as a whole.

The paper is organized in five sections. First, I present a brief description of Transmilenio and the evolution of the map until 2006. Second, I analyse what I call the clash of expertises – between communications experts, operations experts, and various groups of users. Third, I discuss some of the roles of the many users that participated in the process. Fourth, I deal with issues of representation and the iconic character of urban transportation maps. At the end, I conclude and elaborate on some further lines of enquiry.

The Map of Transmilenio

On 29 April 2006, the growing system of Transmilenio began operating with a whole new map and signage. The confusion among users was so great that passengers began filling up the narrow stations without taking any bus, because they simply could not understand which bus would take them to their destination. In some key stations, the overcrowding reached critical levels, and the police had to intervene to avoid rioting. In the control room of Transmilenio, operators quickly set up a crisis room, where the managers could openly discuss the situation and take action. It was the worst crisis that Transmilenio staff experienced and had to handle.

Why did the Transmilenio staff change the map overnight? Why did they have to face such confusion among passengers? A detailed history of the design of the Transmilenio system is available elsewhere (Ardila-Gomez, 2004; Valderrama, forthcoming 2010). Here, I want to concentrate on the elements that make the map issue so relevant.

Transmilenio is the first bus rapid transit system (BRT) to achieve mass transit performance. This means that it is the first bus system that can compete in capacity with heavy rail systems. When the first line came into operation in 2000, the system carried 790,000 passengers a day; by the 29 April 2006, it was carrying 1.2 million passengers; today, it moves over 1.5 million passengers a day.[7] The basic principle of operation of a BRT like Transmilenio is that it uses high capacity buses, dedicated lanes and bus stations with level access. Additionally, the combination of regular and express routes allows the system to reach mass transit capacity.

Figure 1 shows Avenida Jiménez Station in central Bogotá. The station is composed of three wagons.[8] In each wagon, one or two buses can stop at the same time. The picture shows two of the three wagons this station has in the Avenida Caracas. In this station, up to four buses can stop and exchange passengers with the station at one time in each direction, while another four or five buses are overtaking in each direction. Because the

[7] Just for comparison, note that the London Underground moves 3.4 million passengers daily; the Metro in Santiago de Chile 2.5 million; and the Metro in Washington around 800,000. The whole S-train network of Copenhagen plus its metro moves 415,000 passengers daily.

[8] The word wagon refers to a part of a train for train systems. However, for Transmilenio, this word defines the different sections of the bus stations. In fact, some trains usually separate along the way, so that passengers board a specific wagon to come to a certain destination. I have experienced this in intercity trains in Holland and in Denmark. In Transmilenio, the wagon is also related to the destination, but instead of being part of the mobile units (the buses), it is part of the fixed units (the stations). Later in the description, I explain how this arrangement came about.

buses have four sets of doors on the left side, stopping for passengers is quick. Each bus can carry up to 160 passengers, which they often do. This combination accounts for the high capacity of the system. In other words, if the system had only regular services, buses that stop at all stations, it would not achieve mass transit capacities (i.e. more than 20,000 passengers per hour in the most loaded direction). However, the combination of regular and express services poses a problem of communication, because any given route has many services. Therefore, a traditional train or underground map does not work for Transmilenio. In this paper, I explain why, and how different experts and users tried to solve this problem.

Figure 1. Transmilenio Avenida Jiménez Station

Figure 2 shows one of the first maps of Transmilenio. This map was designed by the engineers and planners who developed and initiated the operation of the system. It resembles any other transportation map, but it has the additional information in the squares and the circles. The squares with number 1 inside indicate that route number 1 stops at all those stations. The circles with numbers 10, 20, 30 and 40 designate the express routes that stop only at a few stations. The routes are symmetrical, as they are in the majority of train systems. This means that they stop at the same stations in both directions. This map already simplifies the shape of the city, but it still tries to preserve two salient city features: first, the top of the map is the east geographic direction, which is the tradition for many Colombian city maps (more on this issue below); and second, it tries to show the curvature of the Avenida Caracas towards the south.

Figure 2. One of the first maps of Transmilenio 2001

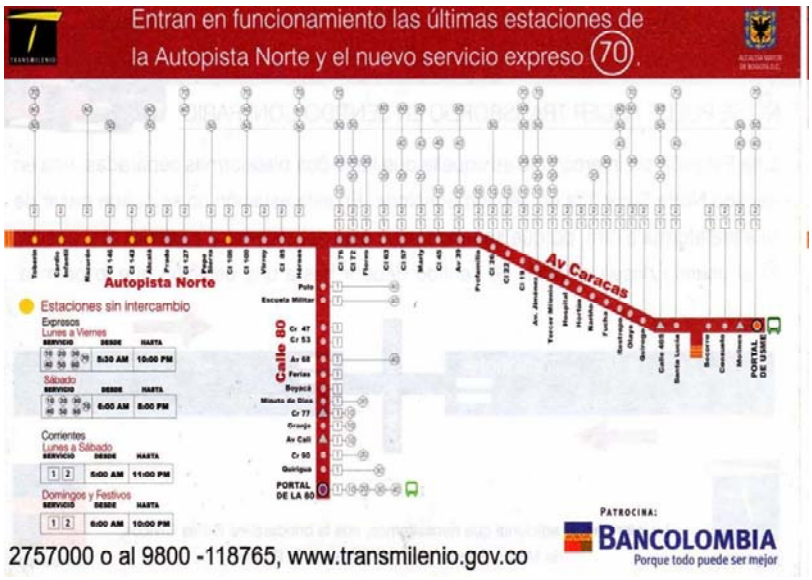

Figure 3: Map of Transmilenio once operation began in the Autopista Norte

Figure 3 shows how the map and the system changed when the extension of Avenida Caracas to the north, the Autopista Norte, began operating. The Transmilenio experts preserved the principles of the previous map, but they also specified a new schedule for the express routes, which were restricted to weekdays and Saturdays and to a certain schedule covering peak periods. The aim of restricting the schedule of services is to maximize the management of the fleet of buses in order to avoid having buses running at low capacity late at night and on Sundays. At this stage, the maximization was quite timid, but with time, operators emphasized this optimization strategy. There was an economic reason for doing so. Transmilenio is a public-private partnership. The planning and control of operations are performed by a public entity: Transmilenio S.A. But private firms own and operate the fleet of buses. The private companies' income depends on the number of passengers they carry in their buses and the number of kilometres their buses travel. They are also heavily fined every month, if they fail to comply with a certain quantity and quality of service. Therefore, they have an incentive to pursue maximal exploitation of the fleet. The operational experts of the coordinating

agency were also just as keen to pursue this maximization, because this is the one feature that makes a BRT competitive. This requires a good deal of transport engineering and computer modelling – the power of technology – and as the system grew, the operation was refined. Figure 4 shows a later map, with even more express services. Some of these services were restricted only to peak hours on week days (yellow and blue stripe), and a few new express services were designed only for Sundays.

Figure 4. Map of Transmilenio, circa 2004

In Figure 4, the map is improved to become a geometrically simplified representation of the main corridors. The experts also introduced some colours to differentiate between the different routes of the system. This is recognizable as a modified route-based transport map.

In 2004, the operation and communication experts of Transmilenio S.A. already saw that with the further growth of the system, the system map would be insufficient, especially when the second phase of the system began operating in 2006. Although users assessed the communication strategy of the system positively, Transmilenio S.A. hired Steer Davies and Gleeve (SDG) to perform an assessment of the signage of the whole system. Since 1998, SDG has been a very close consultant partner to Transmilenio. The current head of SDG in Colombia, Germán Lleras, is one of the former designers of the system. However, their local expertise was primarily in the areas of operation and transportation. Therefore, consultants from SDG's headquarters in London were invited to Bogotá to perform the assessment. These experts assessed the system to have a very poor signage strategy; from a communication point of view, it was too complicated for the user, and this would become worse with the growth of the system. Figure 5 shows one of the last maps used with the old visual paradigm. For many, it simply did not work; there was too much information to put in one single visual representation. Furthermore, it was next to impossible to highlight the different express routes stopping at the stations where two or more lines met. Both communications experts and operations experts within Transmilenio and SDG understood clearly by this time that with further growth of the system, a completely new visual strategy was needed.

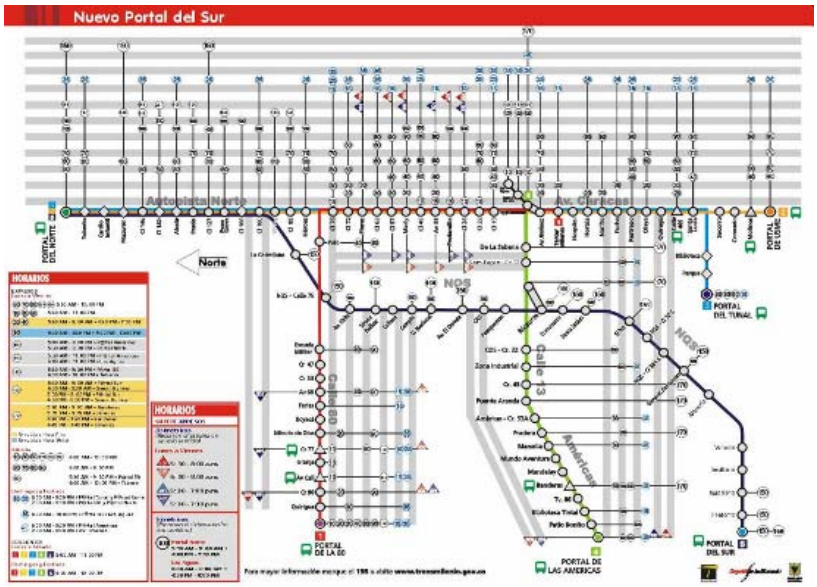

Figure 5. Pilot map for Transmilenio when the second phase started operation

The clash of expertises

It is during the process of defining what were the appropriate signage and communication strategies for Transmilenio that tension emerged between different groups of experts and types of expertise. First, there were the communications experts, (CEs) both at SDG and in Transmilenio, who based their analyses and recommendations on a long tradition of visual design and on the principles of wayfinding (Gibson, 2009; Mollerup, 2005; Smitshuijzen, 2007). This group was composed mainly of experts trained in visual design. Second, there were the operations experts (OEs) in Transmilenio and SDG who were mainly trained in transport engineering. This group led the refinement of the operations and the fleet management of Transmilenio for years. They have the merit of making the system operate at minimum cost (Transmilenio's operation is not subsidized by the city), while also maximizing savings in travel time for passengers. They have achieved this through careful measurements of the travel patterns of passengers, using transport engineering tools, such as origin-destination matrixes, and developing computing algorithms to model the best combination of express routes at different times during the day.

Third, there were the passengers of the system, and also some observers of the system from various places around the world. Oudshoorn and Pinch (2005) state that there are a wide variety of users, and that analysts should not foreclose their roles beforehand. Although there are many theoretical approaches that still conceive of users as passive actors who either accept or reject designs (Akrich, 1992), other roles are increasingly being accounted for. Oudshoorn and Pinch (2005) summarize some of the categories developed: end users – in this case, the private operators of Transmilenio, observers of the system, and the passengers who actively discuss the system; lay end users – in this case, the passengers of Transmilenio that accept the system as it is; implicated users – in this case, those users that are excluded from the system for various reasons (see Valderrama, forthcoming, for an analysis of accessibility to Transmilenio); and

concerned groups of users. Callon and Rabeharisoa (2008) have introduced the notion of concerned groups to account for the way organized users can influence knowledge production and design processes. To follow these theoretical developments, I present here the many ways in which different user groups of Transmilenio and expert groups within the Transmilenio's organizational network influenced the design of the map of the system from 2005 onwards.

During 2004 and 2005, operations experts, OEs, and communications experts, CEs, worked together to assess the system and devise a new strategy for Transmilenio as a whole. CEs noted for example that the signage of the system was very poor. There was no color differentiation of the different signs. Visually, the exit sign was very similar to the sign intended to indicate the bus services that stopped at a given wagon. User assessment of the system was however positive, which experts explained was because the main user of Transmilenio was a commuter that used the same services regularly. This characterization of the user was used several times, especially by the OEs, as an argument to support their resistance to many of the proposals made by the CEs.

The CEs, on the other hand, performed several interviews with users and defined an alternative set of signage and representation of the system (Steer Davies and Gleeve, 2005). In this sense, the map of the system was just one part of a larger effort to improve the navigating environment of the whole system. This effort included modifications in the signage at the stations, inside the buses and in all the communication media, especially printed maps and map displays at stations.

The whole process took around two years, but here I want to concentrate on the essential tension that developed between CEs and OEs. CEs applied the principles of wayfinding; they propose that a user (a walker, a driver, a public transport passenger) normally feels comfortable and safe using only a few routes – no more than four or five – to reach a desired destination. If forced to use a different route, the user feels insecure and unsafe. Therefore, from a wayfinding point of view, the user should be provided with the simplest and clearest information possible. Because all movement is complicated, wayfinding experts have developed the principle of "information segmentation", which is basically to break up information in order to provide it to the user where it is necessary (Gibson, 2009; Mollerup, 2005; Smitshuijzen, 2007).[9]

From this point of view, a person needing to go from one place to another in Bogotá (or any other city that has a transportation system) first needs to know where the closest station is; when she arrives at the entrance to that station, the user needs to be able to clearly identify which station it is; once inside the station, she needs to be informed in which wagon and door she will find the service that takes her to her destination; and when she arrives at the door, she needs to be able to identify which service is the fastest (Steer Davies and Gleeve, 2005). This is exactly what was proposed for Transmilenio: the proposal was to extract all the different information provided by the now too complicated engineering map (Figure 5) and give to the passengers at different places inside the station. It was also proposed to reassign the wagons and doors inside the

[9] These references are of books published after the events I am analysing in this paper. However, they are representative of the kind of knowledge people from the signage and wayfinding communities draw for their designs. The references were actually provided by one of the interviewees, Phil Berczuk from SDG.

stations to correspond to the different parts of the city. So in any given station in the centre of Bogotá, for example, a specific wagon would be assigned to those services heading to Suba; a different wagon for those going to Autopista Norte, and so on.

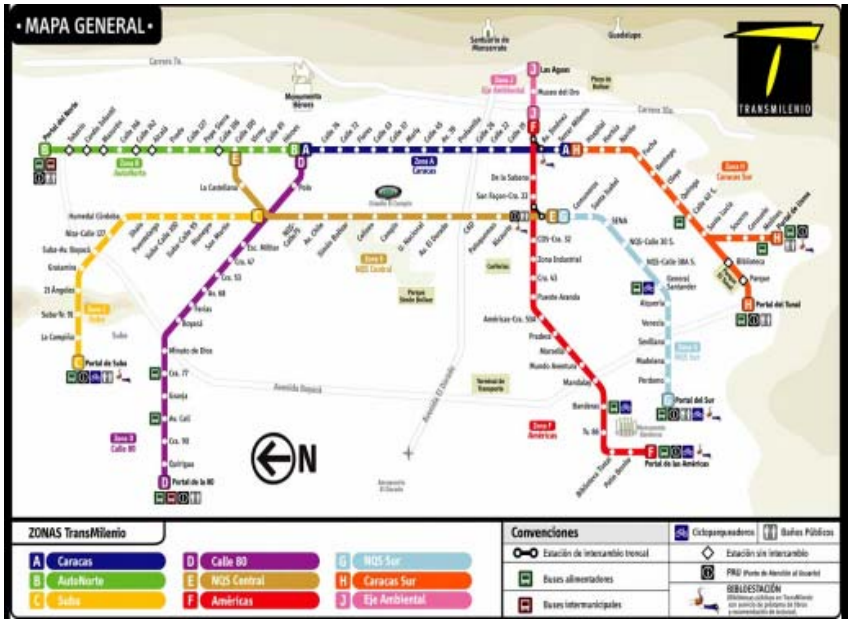

Figure 6: Mapa General of Transmilenio

OEs accepted the general recommendation of the CEs, but became critical of two aspects: one, they did not think it was possible or desirable to segment all the information. It was their opinion that passengers needed to "see" the whole system in order to plan their trip, especially information about express routes. And they wanted to preserve the flexibility of the system: the possibility of changing express routes, of refining the system in order to anticipate user needs, to maintain and, if possible, decrease passengers' average travel time. Since the start of phase 2, asymmetrical routing had been introduced into the system, meaning that a route does not have the same stops in both directions; actually, a given route only exists in one direction. So, unlike service 10 in the first phase of Transmilenio, which stopped at the same stations in both directions and was scheduled for the whole day, route B61 in phase 2 only travels from Suba to Autopista Norte on weekdays from 4:30 to 7:30 pm; and so on, for a total of 78 different services in the whole system.

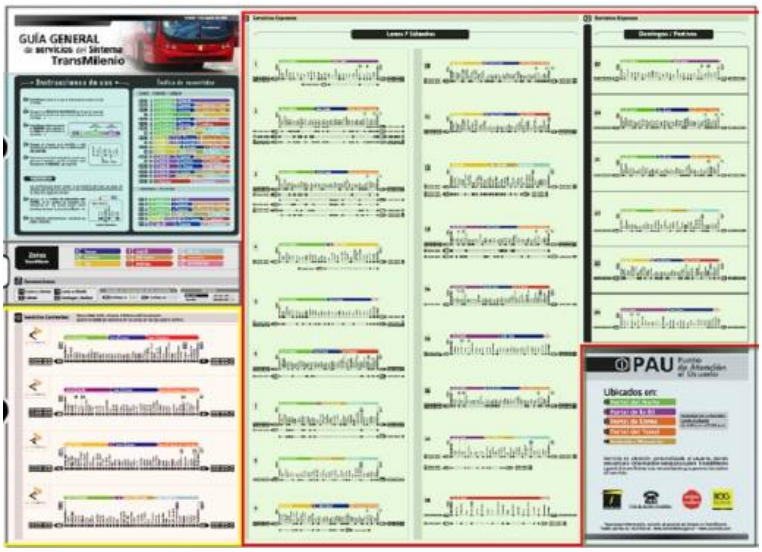

Figure 7. Guia General of Transmilenio

The end result of the tension between OEs and CEs was that the information in the previous maps was disaggregated into two different displays. Figure 6 shows the Mapa General of Transmilenio. This is a very minimal representation of the system, featuring only the main trunk lines divided into coloured and tagged zones. In the previous map (Figure 5), the user could find the exact combination of services in order to reach her destination. The new map does not provide that possibility; it is not sufficient, and according to the CEs, it was not meant to be sufficient – an additional display is required, the display shown in Figure 7. This display is really complicated, and passengers need training to be able to read it. But in this display, it is possible to find information on all Transmilenio's services for weekdays, Saturdays and Sundays: a total of 78 different services. From the point of view of the OEs, this is an achievement, since it provides any given passenger with an overview of the system. For the CEs, this is not an achievement, because the display is very confusing. Although it does not betray the general spirit of the communication and signage strategy, it does overload the passenger with too much information. Actually, many passengers have learned about the routes they use regularly but are still unable to read the maps.

Users' roles and influence

One can distinguish four different groups that entered the process and influenced or attempted to influence the result. They are: first, the users that were interviewed by SDG and Transmilenio experts and participated in the trials of the different versions of the map; second, the informed users and observers who suggested improvements through various forums, like the discussion boards at www.skyscrapercity.com; third, the owners and designers of surumbo.com; and finally, the domesticated passengers, who once they overcame their confusion and shock began using the system in a disciplined manner.

CEs from Transmilenio and SDG used the methods of focal groups, interviews and surveys to collect information about the signage and the navigating tools of Transmilenio. The data collection process was conducted in 2004 and 2005 (Steer

Davies and Gleeve, 2005: 2). The researchers also set up a test station to test the users' understanding of three different types of maps: a line-based map (Figure 8), a route-based map (Figure 9) and a zone-based map (a preliminary version of Figure 6 above). It is interesting to note that on the basis of the experts' observations and the activities with users, it was not conclusive that any one of the three options was better than the other two – they were all actually very confusing ((Steer Davies and Gleeve, 2005: 11-15). Therefore, the first recommendation was for Transmilenio S.A. to conduct a massive education campaign for the new signage and map.

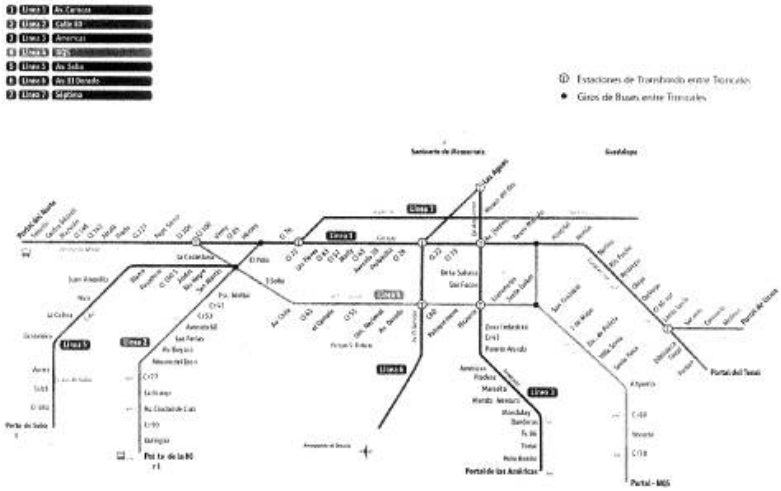

Figure 8: Map based in coloured lines proposed by SDG (Steer Davies and Gleeve, 2005)

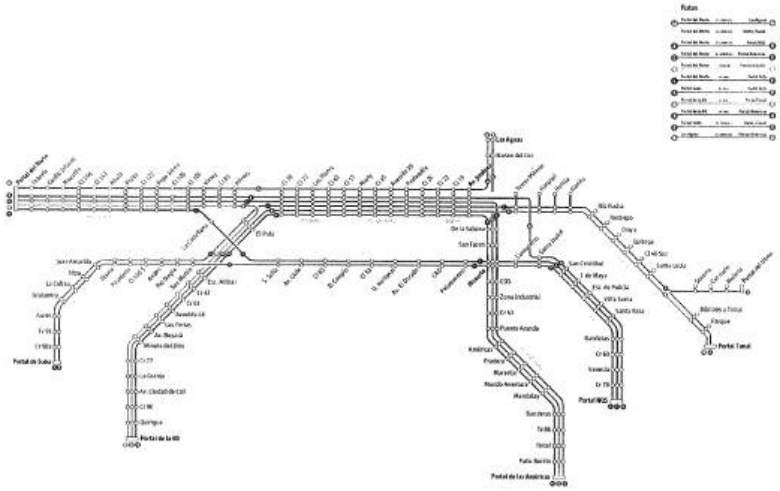

Figure 9: Map based on routes proposed by SDG (Steer Davies and Gleeve, 2005).

CEs recommended the use of a zone map, however, as it was the one map that allowed the design of hierarchies of information, since the whole set of signage accompanying the zone map was most easily understood (Steer Davies and Gleeve, 2005:15). This map was only one element in the whole set of proposals of how to signage the system and how to display information inside stations. It is thus clear that passengers participated in the process of designing the new signage strategy for Transmilenio, and that they influenced the decision to use a zone map.

Another group that tried to influence the process was a qualified group of users that exchanged information through a discussion board at www.skyscrapercity.com between February and April 2006. This group of people, some of them living in Bogotá and some in other places, exchanged information and opinions about the design of Transmilenio and the development of the new phases. It is clear that one of the participants had connections with Transmilenio S.A. and had in fact established a unofficial Transmilenio web page of (http://juliomb179.googlepages.com/). One other participant, an architect, actually developed his own proposal for a new map for Transmilenio that changed the geographical orientation to the north and also changed some station names to better fit the neighbourhood it belonged to. This map proposal (Figure 10) was a line map similar to the one considered by SDG in Figure 8.

It is not my intention to claim that these users actually influenced the design of the map, but the discussion board and the quality of the information exchanged show that some users and observers of the system actually had contributory expertise (Collins and Evans, 2002). In other words, they could have participated in a qualified discussion about the map developments if they had actually been invited to do so.

A third group of users of the map of Transmilenio comprises the owners and operators of the webpage www.surumbo.com. This company delivers an online information service for travellers regarding what buses or combination of services they can use to get from one part of the city to another. The company became a strategic ally of Transmilenio S.A., and an agreement was made whereby Transmilenio would supply all the operational information to www.surumbo.com. In return, this company was allowed to sell advertisements on their webpage as a source of income.
Passengers have become active participants, recommending ways of improving the webpage and suggesting corrections to the data. Some of the suggestions have been implemented by www.surumbo.com, when they are the ones to make an improvement. Other suggestions have been sent to Transmilenio S.A., since they concern the operation of the system and not only the information.

The majority of the suggestions for new routes or rescheduling have received a more or less standard answer from Transmilenio S.A., stating that operations are based on careful measurements of the origins and destinations of passengers, optimized to provide the fastest trips, on average. This standard answer reveals a desire on the part of Transmilenio S.A. staff to domesticate the passengers and make them accept the system as proposed, rather than considering changes.

This attitude was confirmed by OEs, who had also expected that passengers would become able map readers and would stop asking the staff at stations how to get from one place to another.

Transmilenio passengers also participated actively in both expressing their demands to Transmilenio through open participatory channels and occasionally blocking the system when their needs were not met. However in general , they have been disciplined users; and not only that – they have contributed to improving the functioning of the system. After the initial shock from changes that were introduced overnight on 29 April 2006,

but which were incomplete, passengers have learned to use the system, which is operating normally until today.

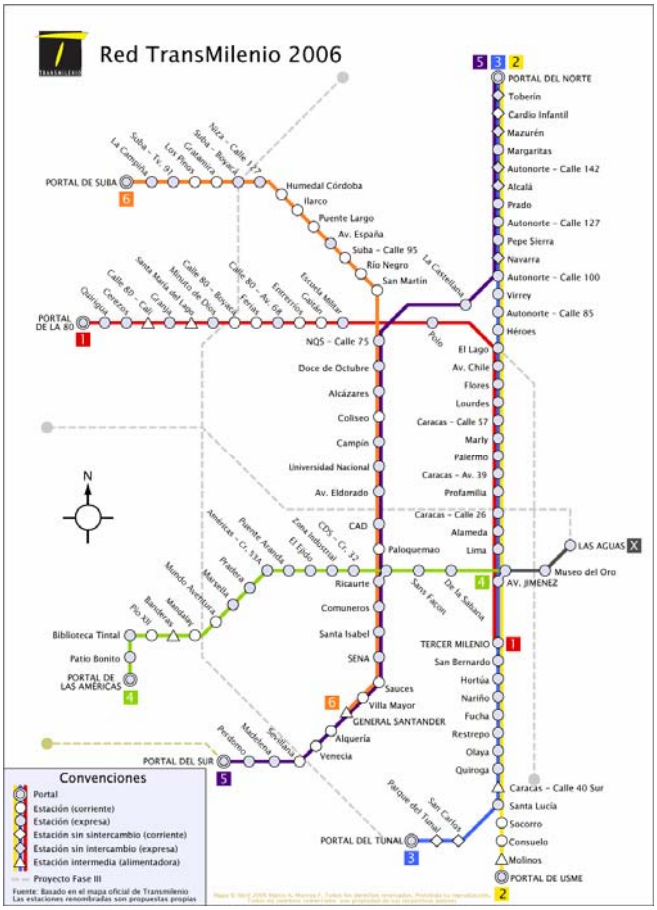

Figure 10. Map elaborated by Marco Monroy and presented at the forum on Trasnmilenio at http://www.skyscrapercity.com/showthread.php?t=322222&page=6. Accessed 3 February 2010.

To summarize, it is evident that the map of Transmilenio is the result of configurational work carried out by experts, observers, expert users and end users, all interacting in various ways. In the narratives above, an element of identity is also noticeable: "Technologies might create new identities, or transform or reinforce existing identities, by delegating and distributing specific responsibilities, skills and tasks to users" (Oudshoorn, Rommes and Stienstra, 2004: 32). In this case CEs, OEs and the various user groups all change their identities subtlety. They pose new demands to one another. Very explicitly, OEs expect that passengers become able map readers. CEs would rather simplify operations in favour of easier navigability. And expert users and observers confirm that their suggestions are welcomed as long as they do not mess up the origin-destination measurements and optimizations. They are all struggling to define the system, and few are conscious that they are also re-defining the city of Bogotá.

Representation, Maps and the City

Urban transportation maps play a key role in the actual functioning of the system. They are crucial elements of the sociotechnical system; they are of extreme central importance. A bad map or an absent map can stop the system. Although they are inscriptions whose development is heterogeneous and contested –as shown above – they also become powerful organizing devices that transcend the system itself. Janet Vertesi's conclusion regarding what is in practice the London Underground Map can also be applied to the Transmilenio Map: It becomes a powerful organizing representation of the city of Bogotá itself (Vertesi, 2008).

A significant tradition in urban studies and urban history shows that the city is much more than physical conglomerates (e.g. Farias and Bender, 2009). The city also exists in discourse, in events, in travel catalogues, as global examples of this or that achievement or of this or that tragedy or misery. Cities also exist as statistics and so on and so forth. And they also exist as images (Lynch, 1960). Lynch proposes five constitutive elements that structure cities from a physical point of view: paths, edges, districts, nodes and landmarks. Bogotá grew from a small town that was settled just beside a beautiful mountain chain, running from the south toward the north. In the 16th century, the Spanish conquerors quickly built a church on top of one of these mountains: Monserrate. As maps of the city began to be made, it is most probable that the mapmakers chose to situate the church of Monserrate at the top of the maps; therefore, maps of Bogotá have traditionally been oriented toward the east.

At the end of the 19th century, the city administration adopted a numerical nomenclature to organize the city. The streets Bogotá running parallel to the mountains were called *carreras*, and those that were perpendicular to the mountains were called *calles*. Thus, the address Calle 118 # 52-40 is located in *calle* 118 north (if it were south, there would be an S after 118), with *carrera* 52 more or less 40 meters away from the corner. This is not a simple system, but it has enabled the city to function without a map. London and Copenhagen are cities where maps and books with pages and pages of indexed street names are special devices compiled to help people find there way around the city. To put it another way, as an inhabitant or visitor in these cities, I would necessarily have to use the AZ in London or the Krak in Copenhagen to get around, especially if I change my routines or go to places I have never been to before or do not visit regularly. Throughout the 20th century in Bogotá, inhabitants did not need to use maps. They were not important to everyday life in the city. With the Cartesian system and the mountains as a visible reference point, people could find their way around. Bogotá had and still has the mountains, the powerful edge. And of course, some nodes, landmarks and districts, but all these elements were second-level devices for orientation.

The map of Transmilenio has the potential of completely reshaping the way the inhabitants of Bogotá imagine their city. Since its introduction in 2006, the map has become the single most used representation of the city in everyday life. Transmilenio stations are becoming as important as street numbers for making sense of the city, of distances, and of the location of places. Although Transmilenio is not the most used public transportation mode, and ambitions that Transmilenio should cover the whole city have been watered down, the system still has the potential of becoming the most

important structuring element of the city, after the mountains. This is happening because Transmilenio has been overtaking the main trunk lines of the city, playing the role underground systems play in other cities. Statistically, it may not be the most used mode of transport, but its configuration in the current arena of development of the city makes it a powerful actor (Valderrama, forthcoming 2010). The map of Transmilenio could be the most powerful inscription helping the system to consolidate its structuring role. It may happen that this map becomes as important to Bogotá as the tube map in London (Vertesi, 2008).

Conclusions

The process of design of a technological system involves various sociotechnical dynamics. Various studies in Actor Network Theory (Callon 1986, 1987; Latour, 1996; Law, 2001) have proposed new concepts to account for these dynamics, using analyses based on the principles of agnosticism, generalized symmetry, and free association. Valderrama (forthcoming 2010) proposes that different actors interact to define and stabilize specific scripts. The actors thus delegate a series of causes and responsibilities to the scripts. In the case of urban transport systems, the configuration of the scripts and the whole system have a profound impact on the arena of development for transport and thus on the city as a whole. The Map of Transmilenio is one script that reveals interesting details of these processes.

For instance, the map reveals that the expertise needed to define the signage of the system is quite heterogeneous; therefore, the process reveals that many more actors, than just signage consultants intervene in the process. In this paper, I show how the map has resulted from interaction among communication and operation experts and various groups of users. One important finding of the analysis is that the roles of experts and users are not clearly differentiated, and that agency and influence do not belong exclusively to the first group. Following Collins and Evans (2002), this article shows that many user groups certainly have interactive expertise – they could be considered experts under certain conditions – and they certainly have contributory expertise in many regards (see for example Figure 10).

Although the actors involved may think they are discussing only one operating script for a transport system, they are actually discussing what might become one of the most important defining representations of the city as a whole. In fact, while I am writing these lines, the administration of Bogotá is pushing ahead a project to reorganize the entire collective public transport system in Bogotá using Transmilenio as the backbone for organizing the city in zones. It is possible that the whole process profits from the reinforcing dynamic exerted by the map of Transmilenio.

Interviewees

Phil Berczuk, Steer David and Gleeve, London, 4 March 2009 and 21 October 2009.
German Lleras, 20 February 2009, Bogotá, Colombia.
Orlando Santiago, 2 March 2009, Bogotá, Colombia.

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This is a study of the processes of design of large technological systems based on a two-case study: the rapid transit bus system, Transmilenio, in Bogotá, Colombia, and the urban rail system, Metro, in Copenhagen, Denmark. The research focused especially on the process by which designers define material scripts during the conception, construction, implementation and operation of large technological systems.

The main argument is that designers define scripts in a process in which three parallel developments are at play: first, a reading takes place of the history (past, present, future) of the arena of development where the system will be constructed. Second, designers define scripts through the delegation of agency, causes and responsibilities to humans and non-humans, a process in which the limits of the system are also defined and enacted. Third, the process of the definition of scripts implies a reconfiguration of the designing team, the supporting actors and the diverse user groups.

By tracing material scripts, the author accounts for the unfolding of visions, politics and materialities that constitute the system. The analysis contributes to understanding the complex sociotechnical dynamics involved in the design processes of large technological systems by revealing how their constitution produces a reconfiguration of the arena of development of urban transport. This dynamic substantiates the co-evolution of technological systems and the city.

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DTU Management Engineering
Department of Management Engineering
Technical University of Denmark

Produktionstorvet
Building 424
DK-2800 Kongens Lyngby
Denmark
Tel. +45 45 25 48 00
Fax +45 45 93 34 35

www.man.dtu.dk